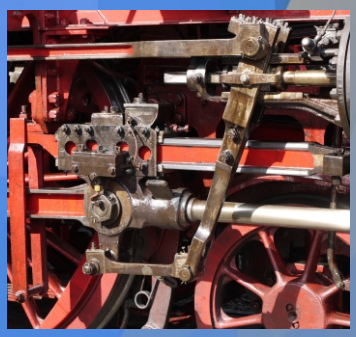
INTERNATIONAL SCIENTIFIC JOURNAL

INDUSTRY 4.0

ISSN (PRINT) 2534-8582
ISSN (WEB) 2534-997X

YEAR VI ISSUE 6/2021






① ② ③ ④

PUBLISHED BY
SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING
"INDUSTRY 4.0", BULGARIA

INTERNATIONAL SCIENTIFIC JOURNAL

INDUSTRY 4.0

YEAR VI, ISSUE 6 / 2021

ISSN (PRINT) 2534-8582, ISSN (WEB) 2534-997X

PUBLISHER

SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING "INDUSTRY 4.0"

108, Rakovski Str., 1000 Sofia, Bulgaria
tel. (+359 2) 987 72 90,
tel./fax (+359 2) 986 22 40,
office@stumejournals.com
WWW.STUMEJOURNALS.COM

EDITOR IN CHIEF

Prof. D.Sc. Georgi Popov, DHC, Technical University of Sofia, BG
Prof. Dr. Dr. Jivka Ovtcharova, DHC, Karlsruhe University of Technology, DE

EDITORIAL BOARD

Members:
Acad. Igor Bychkov, RU
Cor. member Alexey Beliy, BY
Cor. member Svetozar Margenov, BG
Prof. Alexander Afanasyev, RU
Prof. Alexander Guts, RU
Prof. Andrzej Golabczak, PL
Prof. Andrey Firsov, RU
Prof. Bobek Shuklev, MK
Prof. Boris Gordon, EE
Prof. Branko Sirok, SI
Prof. Claudio Melchiorri, IT
Prof. Cveta Martinovska, MK
Prof. Dale Dzemydiene, LT
Prof. Dimitar Yonchev, BG
Prof. Dimitrios Vlachos, GR
Prof. Dragan Perakovic, HR
Prof. Galina Nikolcheva, BG
Prof. Galina Zhavoronkova, UA
Prof. Gerard Lyons, IE
Dr. Giovanni Pappalettera, IT
Prof. Henrik Carlsen, DK
Prof. Idilia Bachkova, BG
Prof. Idit Avrahami, IL
Prof. Inocentiu Maniu, RO
Prof. Iurii Bazhal, UA
Prof. Jürgen Köbler, DE
Prof. Jiri Maryska, CZ
Prof. Katia Vutova, BG
Prof. Lappalainen Kauko, FI
Dr. Liviu Jalba, RO
Prof. Luigi del Re, AT
Prof. Majid Zamani, DE
Prof. Martin Eigner, DE
Dipl.-Kfm. Michael Grethler, DE
Prof. Michael Valasek, CZ
Prof. Milija Suknovic, RS
Prof. Miodrag Dashic, RS
Prof. Mladen Velev, BG
Prof. Mohammed Taleb Obaidat, JO
Prof. Murat Alanyali, TR
Prof. Nafisa Yusupova, RU
Prof. Nina Bijedic, BA
Prof. Ninoslav Marina, MK
Prof. Olga Zaborovskaia, RU
Prof. Pavel Kovach, RS
Prof. Petar Kolev, BG
Prof. Peter Korondi, HU
Prof. Peter Sincak, SK
Prof. Petra Bittrich, DE
Prof. Predrag Dasic, RS
Prof. Radu Dogaru, RO
Prof. Raicho Ilarionov, BG
Prof. Raul Turmanidze, GE
Prof. René Beigang, DE
Prof. Rozeta Miho, AL
Prof. Sasho Guergov, BG
Prof. Seniye Ümit Oktay Firat, TR
Prof. Sreten Savicevic, ME
Prof. Stefan Stefanov, BG
Prof. Svetan Ratchev, UK
Prof. Sveto Svetkovski, MK
Prof. Tomislav Šarić, HR
Prof. Vasile Cartofeanu, MD
Prof. Vidosav Majstorovic, RS
Prof. Vjaceslavs Bobrovs, LV
Prof. Vladyslav Alieksieiev, UA

C O N T E N T S

TECHNOLOGICAL BASIS OF "INDUSTRY 4.0"

Cybersecurity of OPC ua based cyber-physical systems
Tsvetelina Ivanova, Yordan Belev, Idilia Batchkova 204

Sequential development of integrated remote-control Smart Home/Office systems
Georgi Kolev 208

Sterile Manufacturing Quality Control Methods in the Medical Products Industry
Toma Stulgė, Rūta Rimašauskienė 211

Aequor Tracer: Traffic Analyzer for GPON Networks
Lukas Jabloncik, Petr Munster, Tomas Horvath, Vaclav Oujezsky 215

DOMINANT TECHNOLOGIES IN "INDUSTRY 4.0"

Capability of micro-milling in machining of difficult-to-cut materials
Branislav Sredanovic, Djordje Cica, Stevo Borojevic, Sasa Tesic, Davorin Kramar 215

Technology for production of technical products with fixed thickness and made of quartz ceramics by means of a moulding matrix with a silicone insert
Gabriel Peev, Lyuben Lakov, Gergana Mutafchieva, Mihaela Aleksandrova 222

Experimental analysis of creep behaviour of solder alloys at near eutectic point by using indentation test
Irida Markja, Klodian Dhoska, Dervish Elezi, Heinrisch Oettel 225

Real time capturing welding parameters with tracking module
Deyan Gradinarov, Yuri Bijev 229

BUSINESS & "INDUSTRY 4.0"

World technology market: features and current trends
Galyna Zhavoronkova, Vladimir Zhavoronkov, Natalia Kovalenko, Irina Panasiuk 232

Tax challenges of home office regime following the COVID-19 pandemic
Jana Kub icová 236

Cybersecurity of OPC ua based cyber-physical systems

Tsvetelina Ivanova, Yordan Belev, Idilia Batchkova
Dept. of Industrial Automation, University of Chemical Technology and Metallurgy
Bul. Kl. Ohridski 8, Sofia, Bulgaria

t.ivanova@uctm.edu, idilia@uctm.edu

***Abstract**: The IEC-62541 (OPC UA) standard is an important part of the Industry 4.0 reference architecture and is recommended as the only possible communication standard. A particularly important issue that is being addressed is the issue of security. Cyber security is one of the most important challenges for achieving the objectives of the Industry 4.0 initiative and of the associated cyber-physical systems (CPS). The paper analyzes the vulnerability of cyber-attacks and the main threats that threaten the security of OPC UA-based CPS and defines proven and sustainable recommendations for increasing the security of these applications.*

***Keywords**:* CYBER SECURITY, CYBER-PHYSICAL SYSTEMS, OPC UA, IEC 62541, INDUSTRY-4.0

1. Introduction

The rapid development and widespread penetration of information and communication technologies in the industry has led to the emergence of new strategies for the development of the industry in order to increase its competitiveness, such as the German initiative "Industrie 4.0" [1]. Standardization plays a central role in successfully tackling new challenges. The development and adoption of standards reduces the risk for enterprises and encourages the adoption of new technologies, products and production methods. The Industry Perspectives 4.0 study [2] confirms that the first major challenge related to the implementation of the vision is standardization. The main advantage of using standards is that they reflect the state of science and the development of technology and promote mutual understanding and consensus between partners.

Cyber-Physical Systems (CPS) are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core [3]. Their components can be distributed both spatially and temporally, and include complex networks of feedback controllers and real time communication. These characteristics of CPS significantly complicate the cyber security of these systems and require the solution of a series of complex tasks with the application of a combination of various methods and techniques. Cyber security professionals are facing increasing challenges, both in terms of the frequency with which cyber threats occur and in terms of increasing their risk. The impact of malware and cyber-attacks can not only lead to denial of service or theft and diversion of information, but also affect the behavior of the object under control by causing it to behave in a dangerous manner, which can cause accidents and dangerous consequences. With the increasing complexity of cyber-physical systems and system of system, the issues of ensuring the security and safety of these systems are of global importance. There are three main approaches in achieving cyber security: (i) building and using reference architecture, (ii) developing cyber security standards and (iii) applying methods and tools in the field of automation in cyber security systems.

The basic requirement to the CPS for building fast, platform-independent, scalable and secure communications, which can be integrated horizontally and vertically, is fully met by the IEC-62541 standard (OPC UA) [4]. This standard defines a common infrastructure model for information exchange between components (sensors, mechanisms, control systems) and systems (MES, ERP) in the industry. OPC UA supports the following specifications: (i) information model for presenting structure, behavior and semantics; (ii) modeling of messages for interactions between applications and (iii) communication model for data transfer between endpoints. The IEC-62541 standard (OPC UA) is present in the reference architecture for Industry 4.0 - RAMI [5] and is listed as the only recommended communication standard for implementation. Two aspects are the focus of attention in this standard: the use of information modeling tools and the security issues that are covered in the standard. The paper focuses on Part 2 of IEC-62541 (OPC UA) standard [6], which addresses the security issues of OPC UA applications.

The main purpose of the paper is to analyze the vulnerability of cyber-attacks and the main threats that threaten the security of OPC UA based cyber-physical systems and to define proven and sustainable recommendations for increasing the security of these applications. These recommendations are essential for defining and using effective scenarios to increase the security of these applications and create a successful lifecycle model for the development of OPC UA based cyber-physical systems.

The paper is structured in 4 parts. Following the introduction, in part two, the IEC-62541 (OPC-UA) standard, the term security and the security model are briefly presented. Part 3 provides a brief analysis of cyber-attack threats that threaten the security of OPC UA applications. Part 4 systematizes the main recommendations for building secure OPC UA based cyber-physical systems, which can be used to improve their development lifecycle model.

2. OPC-UA and the security model

2.1. Summary of IEC-62541 standard (OPC-UA)

The IEC-62541 standard or also known as OPC-UA (Open Platform Communication - Unified Architecture) [4], which includes 14 parts, presents a new generation of OPC, which replaces TCP/IP communication protocols specific to DCOM, allowing: (1) the use of OPC applications on any operating system; (2) the implementation in all languages; (3) the use of OPC in devices (firmware); (4) to activate WAN (secure Internet/Intranet/Extranet) and (5) to improve the security management. OPC UA combines all previous protocols into a common, unified data model. It offers a complete networked, object-oriented concept for the namespace, including metadata for defining objects. The OPC UA specification defines a service-oriented architecture (SOA) with a set of services described in Part 4 of the standard [7]. The information models in OPC UA form a layered structure, shown in Fig. 1, where the basic information model is at the lowest level. Above the base model are service-specific extensions to the information model for data access, alarms and conditions, programs, historical access, and aggregates. The accompanying specifications are defined above the composition of the general information models. The next layer contains the accompanying specifications, which are domain-specific information models. At the top level of the OPC UA structure, highly refined information models from different companies or suppliers for use in their specific products are defined. The composition of information models can be extended. The information models are defined and explained in Part 5 of the standard [8].

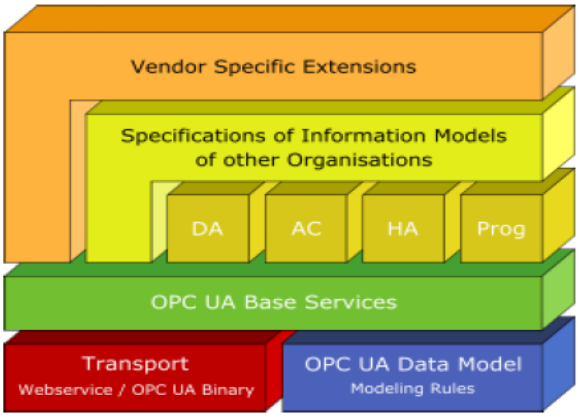


Fig.1: *Multilayer structure of models in OPC UA [8]*

With OPC UA, OPC Foundation makes the transition from object-oriented COM/DCOM technology to service-oriented architecture by integrating previous specifications into a single address space represented by a model for defining complex information in the form of objects consisting of nodes, connected with references. Different classes of nodes convey different semantics. For example, a variable node is a readable or writable value, which has an associated data type that can define the current value. The method node is a function that can be called to be executed. Each node is characterized by attributes, including a unique identifier.

2.2. On the definition of security

In the English technical literature, there are two terms for software security - "assurance" and "security". The term "assurance" looks at security in a broader sense, including its reliability, also known as software resilience, software safety, and its security as "Security", which is the ability of software to resist, tolerate and recovers from events that intentionally compromise its reliability. According to the US National Security Systems Committee's (CNSS) National Information Security Dictionary [9], software security is: "the degree of assurance that software is free of vulnerabilities, either intentionally designed in the software, or accidentally included in any time throughout its life cycle, and that the software functions as intended". Achieving software security affects all phases of the software development life cycle, and the goal of all integrated activities in this direction is to achieve software that shows:

- Trustworthiness - mainly related to the absence of malicious and/or unintentional operational vulnerabilities or weaknesses;
- Predictable execution - there is reasonable assurance that the software, when executed, functions only as intended;
- Conformance - where a planned and systematic set of multidisciplinary activities ensures that software processes and products meet the relevant requirements, standards and procedures.

2.3. Security objectives in OPC-UA

The security model is presented in Part 2 of IEC-62541 [6]. The security of industrial systems is achieved by achieving a set of objectives that are defined on the basis of many years of experience and remain unchanged over the years, despite the ever-changing set of threats to the systems. The main objectives of security are summarized as follows:

- Authentication (A1): Entities such as clients, servers and users must prove their identity. Authentication can be based on something that the entity is, possesses or knows;
- Authorization (A2): Access to read, write or execute resources should be allowed only for those objects that need this access within the system requirements;
- Confidentiality (A3): ensures that users without access rights do not have access to the information, i.e. the data is protected from passive attacks such as eavesdropping, whether the data is transmitted to be stored in memory or stored. To ensure confidentiality, data encryption algorithms using special data protection secrets are used, along with authentication and authorization mechanisms to access this secret;
- Integrity (A4): refers to maintaining the accuracy and integrity of the information, i.e. the recipients receive the same information as the original sender, without the data changing during transmission. Unauthorized changes by authorized organizations or any modifications by unauthorized entities, such as: overwriting, falsification, destruction, involuntary or malicious insertion of logic, deletion, etc. should not be allowed;
- Auditability (A5): actions taken by the system should be recorded to provide evidence to stakeholders that the system is working as intended (successful actions are tracked), to identify the initiator of certain actions (the activity of the user is tracked), to find that attempts to compromise the system have been denied (unsuccessful actions are tracked);
- Availability (A6): refers to the ability of authorized persons to have access to information and timely maintenance of information resources in a state in which they can be used without problems.
- Non-Repudiation (A7): non-repudiation ensures that something that actually happened cannot be said not to have happened. The security service that provides this protection can be one of two types: (1) the recipient of the data receives and stores information proving that the data came from the creator. This blocks the author from claiming that he never sent the data. (2) one in which the sender of the data receives confirmation that the data have been received by the recipient as intended.

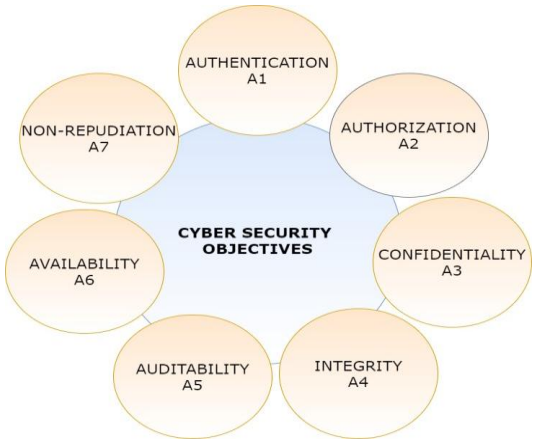


Fig.2: *Cyber security objectives*

Based on the requirements for confidentiality, integrity and availability, a classification of systems and data has been developed, and classes have been defined in accordance with the quality aspects of these requirements. Each class meets a minimum set of security requirements to be met and security measures to be taken. At the heart of this classification are the ISO27001 and ISO27002 standards. The ISO27001 standard refers to the requirements for information security management systems, preparation or selection of lists of known risks, based on various sources of good practice, such as CAPEC (contains a list of 1000 possible attacks), Microsoft's STRIDE, OWASP "Top 10" and many others.

Security is achieved through preventive methods used to protect information from theft, compromise or attack. This requires understanding potential information threats such as viruses and other malicious code. Security risk is a product of three elements: threat, vulnerability and impact. Risk refers to the possibility of loss or damage when a specific threat exploits a captured vulnerability. Risk can include financial losses as a result of business interruptions, damage to reputation, legal

consequences and even loss of life. Vulnerability refers to a specific weakness in assets (resources) that allows a particular attack to be successful.

2.4. OPC-UA security architecture

The standard provides a flexible set of security mechanisms. Client-server communication can be realized in two ways - through and without a session, as shown in Fig. 3. The session is organized in the application layer and in addition to the routine work of client and server applications. It has the task of managing the security, authentication and authorization objectives of the user. The session communicates through a security channel in the communication layer, which is organized in a very flexible way and must be activated. The communication layer provides security mechanisms to achieve confidentiality, integrity, and authentication of the application, using a secure channel that provides encryption to maintain confidentiality, signing messages to maintain integrity, and application authentication certificates. The security mechanisms provided by the Secure Channel services are implemented by a stack protocol that is selected for execution. When OPC UA (UACP) protocols are used, then the security functions are specified in the SSL/TLS mode.

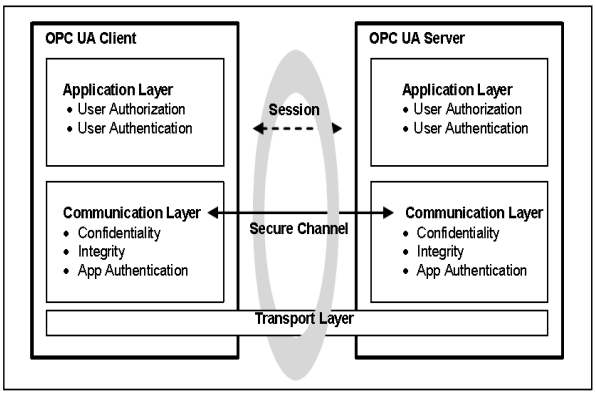


Fig.3: *OPC-UA security architecture for client-server applications [6]*

Communication between applications is based on messages, the parameters of which are defined in Part 4 of the standard and their format defined by *Data Encoding* and *Transport Protocol* (Fig. 4). A stack is a collection of software libraries that implement one or more *Stack Profiles*. The interface between the application and the stack hides the details of stack execution, depending entirely on the development platform used. Each OPC UA *Stack Profile* is a separate application protocol. Even when *Security Mode = None* is selected, i.e. security is not supported, the *Secure Channel* layer is present, supporting a logical channel with a unique identifier.

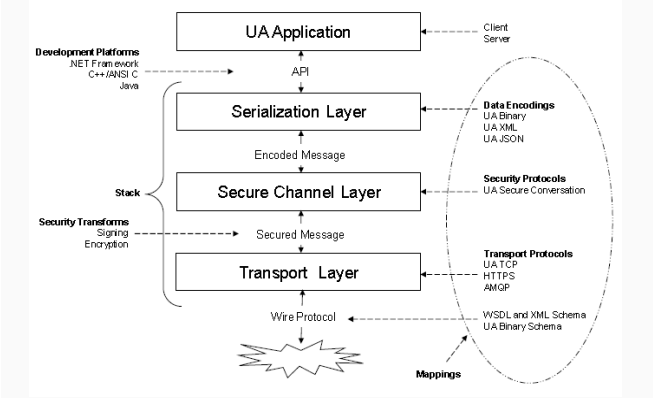


Fig.4: *OPC-UA security architecture for client – server applications*

3. Analysis of threats to OPC UA based CPS

3.1. Defining the main threats

The security of cyber-physical systems reduces the risk of damage caused by attacks. This includes: (1) identifying system threats, (2) identifying system vulnerabilities to those threats, and (3) providing countermeasures that directly reduce vulnerabilities, counter threats, or recover from successful attacks.

OPC UA applications can be used in a variety of operating environments. In some cases, they can be an attractive target for industrial espionage or sabotage, and they can also be exposed to threats through unobtrusive malware, such as worms circulating in public networks with different assumptions about threats and accessibility, as well as different policies for security and application modes. Some of the most common threats to OPC UA based CPS can be summarized as follows:

- Message Flooding: The attacker sends a sequence of requests to the system in an attempt to consume enough server resources to make the system insensitive to legitimate traffic.
- Eavesdropping: listening to other people's conversation or communication without their consent.
- Message Spoofing: A malicious party that impersonates another device or user on the network to launch attacks on network hosts, steals data, distribute malware, or bypass access controls.
- Message Alteration: during the attack, messages are intercepted in the communication environment, and certain information can be changed, or the call can be diverted, the service can be interrupted, etc.
- Message Replay: A network attack in which a valid data transmission is recorded and then played back to affect system operations.
- Malformed Messages: Also known as Protocol Fuzzing, the attack sends messages with the wrong syntax to the target server or client to interrupt the service.
- Server Profiling: Gathers information about the server or related equipment to explore what the core infrastructure is.
- Session Hijacking: When a TCP session is hijacked, the user session is attacked over a secure network. Session hijacking is also known as a "middle man attack" in which an attacker uses a computer program (sniffer) that detects and records a variety of limited information, especially secret passwords needed to access files or networks.
- Rogue Server: A rogue server is a network server that is not under the administrative control of network personnel.
- Compromised User Credentials: User credentials are available to others other than the user (without their knowledge or consent) and may be logged into the user's account.

3.2. Coordinating threats with OPC UA security mechanisms

The coherence achieved between the threats and the security mechanisms of OPC UA, presented in Table 1, links the security functions of OPC UA with specific threats. For example, the following cases are possible (1) OPC UA minimizes the loss of availability caused by flooding with messages by minimizing the processing of messages until they are authenticated, or (2) when eavesdropping occurs, OPC UA provides encryption to protect against eavesdropping, or (3) OPC UA counts threats to tamper with messages by providing the ability to sign messages, or (4) OPC UA counteracts session hijacking by setting a security context, i.e. security channel in each session, etc.

Table.1: *Consistency of threats and security functions*

Threats	A1	A2	A3	A4	A5	A6
Message Flooding						X
Eavesdropping			X			
Message Spoofing		X		X		
Message Alteration		X		X		
Message Replay		X				
Malformed Messages				X		
Server Profiling	X	X	X	X	X	X
Session Hijacking	X	X	X			
Rogue Server	X	X	X		X	X
Compromised User Credentials		X	X			

4. Safety recommendations when using OPC UA

As a result of a number of tests performed in accordance with the standard, the following recommendations have been identified and summarized with a view to the use of secure communications with the OPC UA protocol:

• Operation in "*SecurityMode*": This means that "*Sign*" or "*SignAndEncrypt*" mode must be selected. These modes ensure that, at the application level, authentication is mandatory. "*None*" security mode does not provide protection! The "*SignAndEncrypt*" security mode is used to protect the integrity of data and its confidentiality [10].

• Choice of cryptographic algorithms: "*Basic256Sha256*" must be selected as the *SecurityPolicy* [11], provided that the clients with which the server interacts support this policy. Security policies using outdated algorithms, such as "*SHA-1*", should not be used.

• User authentication: Logging in to the UA server with an "anonymous" ID should only be used when accessing non-critical resources, as in this case it is not possible to track by the server who is changing the data or configuration. Hackers can take advantage of these recommendations to use OPC UA with a Secure Way ID to read or write data in an unauthorized manner. This can happen if the restriction on the rights to work with the "anonymous" identifier is not configured adequately. [10]

• Storing certificates and private keys: The used private keys or certificate files should not be stored in an unencrypted file system. For this purpose, special certificates stores of the operating system and its capabilities for setting access rights must be used. It is recommended to use TPMs (Trusted Platform Modules) or external secure hardware, such as USB authentication tokens to store certificates and/or private keys.

• Use certificates: Connections that do not provide trusted certificates are not allowed. Self-signed certificates require additional verification. If the certificates are not self-signed, the establishment of a certification body is required, and the certificates of the certification body are signed independently or by another certification body. Certification bodies can be multi-layered [5].

• Certificate management and maintenance: It is recommended to use certificate trust lists and certificate revocation lists to manage only valid certificates. These lists are created by trusted users or processes. The lists must be updated regularly.

Conclusions

Digitalization and growing network structures and applications on the one hand, and increasing hacking attacks on critical infrastructures and industrial applications on the other, are placing the issue of network and application security increasingly on the agenda. The analysis and comparison of the capabilities of OPC UA presented in the paper show the ability to successfully deal with security issues at different levels in the automation pyramid. The defined objectives, potential threats and established compliance allow, according to IEC-62541 standard (OPC UA), the development of security profiles and models for individual areas of application.

Acknowledgment: The study was conducted within the National Research Program "Information and Communication Technologies for a Digital Single Market in Science, Education and Security (ICTinSES)", funded by the Ministry of Education and Science.

References

1. Kagermann H., Wahlster W., Helbig J., Recommendations for implementing the strategic initiative INDUSTRIE 4.0, Final report of the Industrie 4.0 Working Group, Akatech, April, 2013.
2. Forschungsunion, "Recommendations for implementing the strategic initiative Industry 4.0", Acatech, 2013.
3. Rajkumar, R., I. Lee, L. Sha, and J. Stankovic (2010), Cyber-physical systems: the next computing revolution, In Proceedings of the 47th Design Automation Conference, ACM, New York, 2010, pp. 731-736.
4. OPC Foundation (2017), OPC UA Specification, Part 1: Overview and Concepts, http://www.opcfoundation.org/UA/Part1/
5. DIN SPEC 91345, Reference architectural model Industry 4.0 (RAMI4.0), 2016, Berlin.
6. OPC Foundation (2018), OPC UA Specification, Part 2: Security model http://www.opcfoundation.org/UA/Part2/
7. OPC Foundation (2017), OPC UA Specification, Part 4: Services http://www.opcfoundation.org/UA/Part4/
8. OPC Foundation (2017), OPC UA Specification, Part 5: Information Model, http://www.opcfoundation.org/UA/Part5/
9. Committee on National Security Systems, National Information Assurance (IA) Glossary, CNSS instruction No. 4009 (revised June 2006). Available from: http://www.cnss.gov/Assets/pdf/cnssi_4009.pdf
10. Fiat, Störtkuhl, Plöb, Zugfil, Gappmeier and Damm, "OPC UA Security Analysis," Federal Office for Information Security, Bonn, Germany, 2017.
11. OPC Foundation (2017), OPC UA Specification, Part 7: Profiles, http://www.opcfoundation.org/UA/Part7/

Sequential development of integrated remote-control Smart Home/Office systems

Georgi Kolev*
University of Chemical Technology and Metallurgy, Bulgaria
*georgi.i.kolev@abv.bg

Abstract: *An integrated smart home system for monitoring and management of the elements of the working environment or at home in Home Assistant platform and is integrated with a voice assistant (Google Assistant) has been developed. It allows monitoring and control of various parameters of the environment, determination of geolocation, tracking the state of the connected devices, provides ascertainment of conditions or constraints during the implementation of logical algorithms or actions, etc. The developed integrated system solves the problem of using various interface applications, communication protocols and standards by integration of all its elements in one Application Programming Interface (API) and simultaneously expanding its scope through integration with a voice assistant (Google Assistant). The development of a dataset of interoperable rules integrated in the Smart Home/Office system should be done function by function. This paper is directed toward the sequential development of integrated remote-control Smart Home/Office systems by adding additional functionality to the already developed integrated system.*
Keywords*: SMART HOME/OFFICE, INTERNET OF THINGS, HOME ASSISTANT PLATFORM, VOICE ASSISTANT.*

1. Introduction

An integrated smart home system for monitoring and management of the elements of the working environment or at home in Home Assistant platform [1] and is integrated with a voice assistant (Google Assistant) has been developed [2, 3]. The structure of the Smart Home/Office system is based on the concept of the Internet of Things (IoT), which includes connectivity of devices and actuators, as well as the presence of Wireless Sensor Network (WSN). It allows monitoring and control of various parameters of the environment, determination of geolocation, tracking the state of the connected devices, provides ascertainment of conditions or constraints during the implementation of logical algorithms or actions, etc. The developed integrated system solves the problem of using various interface applications, communication protocols and standards by integration of all its elements in one Application Programming Interface (API) and simultaneously the system is expanding its scope through its integration with a voice assistant (Google Assistant). The functions of the system include performing actions by request from the users, but also predefined (default) values and actions. The development of a dataset of interoperable rules integrated in the Smart Home/Office system should be done function by function. This paper is directed toward the sequential development of integrated remote-control Smart Home/Office (SH/O) systems by adding additional functionality, including intelligent data analysis, to the already developed integrated system. This process can continue without limitation in time as far as the imagination of the designer and/or the users reaches.

2. Integrated Smart Home/Office system

Depending on the specific operational function, both connected devices or actuators and sensors can be used in the operation of the system to detect the presence or absence of certain conditions, followed by appropriate specific actions. They are realized on the basis of the logical algorithms introduced in the system. The general view of the developed integrated system [4] is presented in Fig. 1. The most frequently used data on the condition of the home and the members of the household are presented there. All objects included in the current integrated SH/O system are over 100, and historical data about them can be traced for a given period of time through the option "History" (Fig. 2).

The built system also includes services available through Home Assistant as presented in Fig. 3 estimation of the time for driving between two points - for example, from to the office, based on the Waze application. Other possibilities are creating a calendar with tasks or a list of purchases available to all members of the household (Fig. 1).

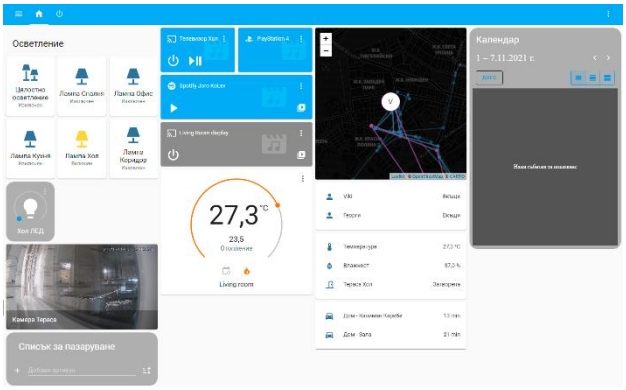


Fig. 1 *Google Home synchronized integrated system.*

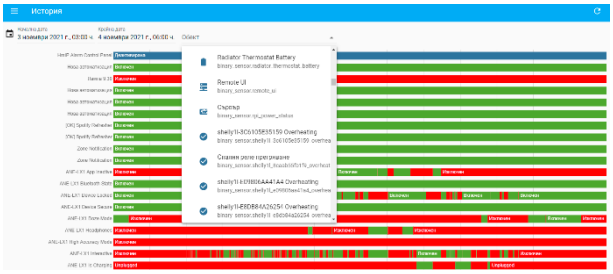


Fig. 2 *Historical data.*

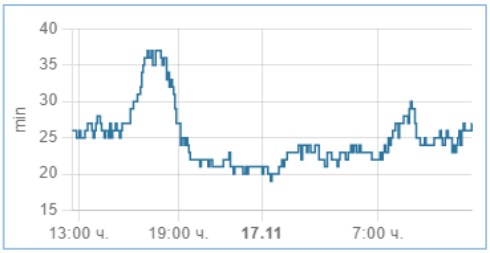


Fig. 3 *Estimation of travel time by car between home and office – Waze [5].*

The functions of the system include performing actions on request by users, but also on predefined values and actions. The development of a set of data from interoperable rules integrated into the Smart Home system must be performed function by function. The structure of a standard interoperable rules can be represented as follows:

"If Condition (& Condition2,…), THEN Action (Action2,…)"

"IF Condition11 (& Condition12,…), then IF Condition21 (& Condition22,…), ……THEN Action (Action2,…)"

The conditions can be set by the user (directly or in time) or depending on the values obtained from the sensors (Sensor-based Linked Open Rules). When analyzing the patterns of the behavior

of the inhabitants of the Smart Home from the collected data, it is possible to offer additional built-in functions [4].

The MQTT (Message Queue Telemetry Transport) protocol is used to ensure the connectivity of the elements in the integrated system and the connected applications, for which many implementations are available. This is a two-way communication protocol through which connected devices can publish data from sensors and at the same time receive configuration information or control commands.

3. Functionality and structure of SH/O system

The presented in the current paper integrated SH/O system integrates the following general functions [2-4]:

- Security – video surveillance, sensor monitoring, fire and flood detection;
- Comfort – remote and/or intelligent control of lighting, curtains, switching on and off appliances, control of video and audio equipment, TV, PlayStation, temperature control – air conditioning, heaters and central heating;
- Healthcare – measurement of environmental indicators – temperature, light, pressure, humidity, CO_2 content, dust, smoke, alarms or reminders for medications;
- Energy consumption and efficiency – consumption of electricity and heat (central heating).
- Indoor care – cleaning, ventilation, air purification and humidification, pet feeding.
- Activities organizer – calendar of events and tasks (individual and common), shopping list, traveling information (Waze), suggestions for spending the holiday time;
- Information – information from the connected mobile phones – geolocation, activities, settings, state of the batteries, sensor data, Wi-Fi connection, data transfer quantity etc.; news, weather information, data storage of historical data from all connected objects, sensor data acquisition and processing.
- Voice control integration – the voice communication is realized through the application for Android – Google Assistant, which is connected to Google Home. On the other hand, the open source Home Assistant application developed on the local server (Raspberry Pi) is synchronized via an API with Google Home.
- Remote access and management.

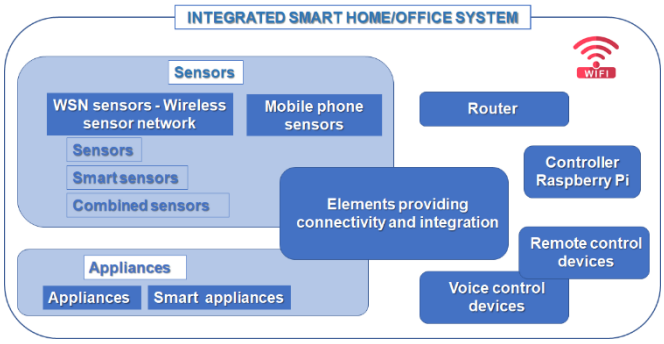


Fig. 4 *Integrated SH/O system elements (devices).*

The described functionality of the integrated system can be successfully applied both in home and in office environment. Each individual project is developed according the individual requirements from the users, connected with their needs, the object specifications – apartment, house, office, their location size, already build or in process of designing or building etc., the selection of its elements and the estimation of its cost.

An overview of the elements integrated in the SH/O system is presented in Fig. 4. Description of the elements can be found in [2, 3].

4. Sequentially expanding of the integrated SH/O system functionality

In order to include additional functions to the developed integrated SH/O system the shown in Fig. 5 algorithm should be followed. Here three cases will be considered:

- Integration of new smart device;
- Development of new function without adding new elements;
- Development of new function, when not all elements are available in the SN/O system.

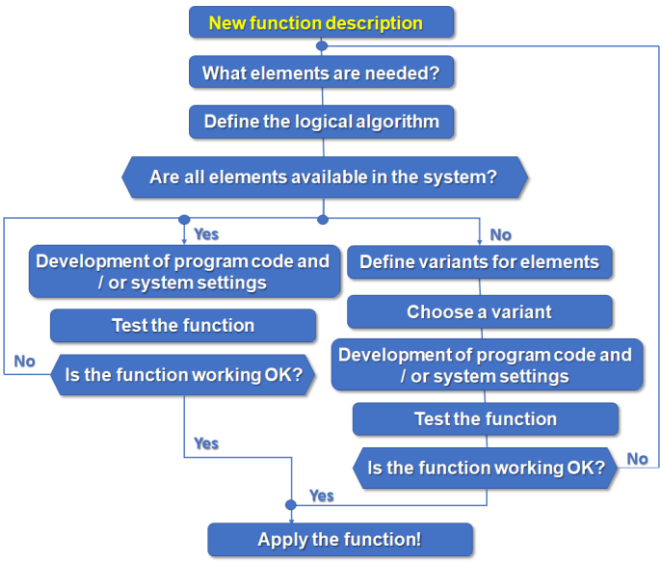


Fig. 5 *Algorithm for new function implementation.*

If a smart device – Canon TR500 series printer must be integrated in the system it should be connected to the Wi-Fi network during the installation of the driver, then the Home Assistant finds the new compatible with the system device, sends notification and the new device can be configured and added to the elements of the SH/O system. This allows the system and the user to monitor the state of the printer, the rate of toner consumption over time and notify the user(s) in advance when the toner reaches predefined level in order to avoid the situation shown in Fig. 6.

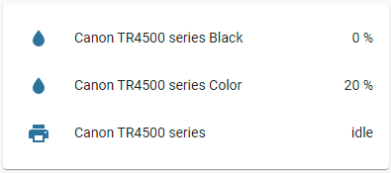


Fig. 6 *State of Canon TR500 series printer.*

As an example for the development of a new function without adding new elements here will be considered the possibility to set the time of for a meeting or an appointment outside the office/home, or waking up in the morning or preparing to go to go work according to the traffic and setting time to prepare (pre-defined time before leaving). In order to set such notification a script defining the arrival time, the time needed for preparation and the target location should be written. That is why it is convenient for repeated actions, like waking up in the morning for work.

The developed function, which uses Waze [5] service for estimation of driving time (*Td*) between two locations, works as it is shown in Fig. 7. For example, the employee should be at the office from 9:00 h. Then the arrival time can be set to *Ta* = 8.55 and the time for preparation is *Tp* = 30 minutes. If the estimated time by Waze is also *Td* = 30 min, then "Notification 1" or the predefined actions (like turning on the lights, playing music, etc.) should be started within the time interval 7:52 ÷ 7:58 a.m. and the "Notification 2" stays in order that the traffic changes and correspondingly the estimated time. If the estimated time for driving

changes to 35 min, then the second notification (or predefined actions) should be started in the time interval 8:14 – 8:20 a.m. The tolerances depend on the frequency of updating of Waze service in the system (current time for update of Waze service is 5 minutes).

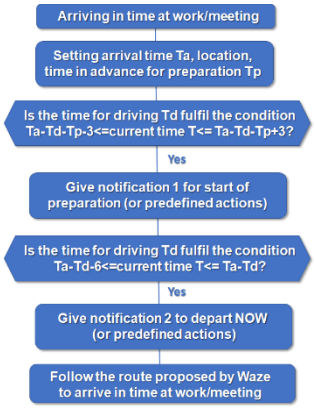


Fig. 7 *Algorithm of arriving in time function.*

The considered here function, which will need additional elements, is a function, which aims to locate if the employee is in the office and if she/he is in her/his workplace. In this case all the elements are not present in the integrated SH/O system (Fig. 5).

The available function is geolocation by GPS in the mobile phones of the connected devices (Fig. 8). In work environment using this function is connected with the availability of business mobile phones of the employees, that can be integrated in the company integrated system, with the knowledge and agreement of the employees.

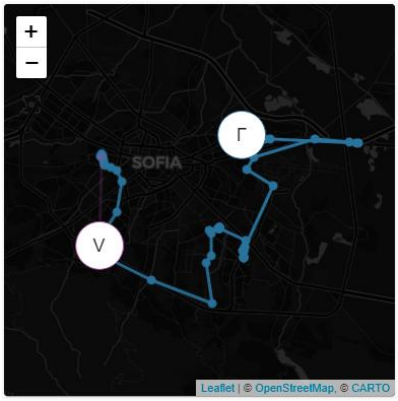


Fig. 8 *Geolocation determined by GPS in a mobile device.*

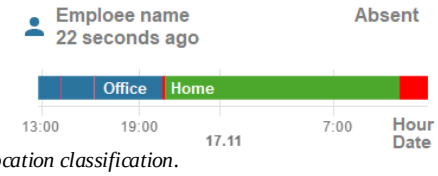


Fig. 9 *Geolocation classification.*

The classification in this case can be done – "in the office" and "out of the office" (Fig. 9).

Another solution, based on Bluetooth connection, is presented in Fig 7. It includes TUYA Bluetooth Gateway and GPS trackers. If the tracker comes into the range of the Bluetooth Gateway it will be registered in the system and the employee can be considered as located in the office. There are different models of trackers and gateways and an appropriate solution should be chosen, depending the size of the office, the number of employees etc. The chosen TUYA Bluetooth Gateway ensures connectivity to the Wi-Fi network and to the SH/O system, besides of Bluetooth devices (trackers), but also of the devices, that use Zigbee communication protocol.



Fig. 8 *TUYA Bluetooth Gateway and GPS trackers.*

The other part of the function is connected with the location of the employee on her/his workplace. This question depends on the type of work of the employees and is not necessarily connected only with the efficiency of the work process, but also can indicate the time the employees sit without movement on their computers (workplaces). In the COVID-19 pandemic the time people, including children, stay behind the computers drastically increases. It is important to add some motion and interruption of the work process in order to let the body and eyes rest.

The integrated SH/O system in this case can register the time spend on the workplace and also can send notification to the employees to interrupt their work for a while and have a rest.

The detection for this function can be done with one or two PIR sensor per employee (Fig. 9), depending on the number of people in the office. The suggested solution is placing the sensor below the desk plate and measurement of the time without movement after registering motion. The suggestion is that, if no motion occurs in the period of 5 minutes, for example, the employee has left his/her workplace.

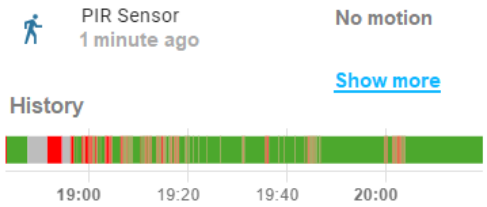


Fig. 9 *PIR sensor historical data.*

In our case the solution with Geolocation, determined by GPS in a mobile device, is appropriate and chosen for realization.

5. Conclusions

This paper is directed toward the sequential development of integrated remote-control Smart Home/Office systems by adding additional functionality, to the already developed integrated system.

Three cases of sequentially expanding of the integrated SH/O system functionality are considered: integration of new smart device, development of new function without adding new elements and development of new function, when not all elements are available in the SN/O system.

The process of the sequential development of integrated remote-control Smart Home/Office systems can continue without limitation in time as far as the imagination of the designer and/or the users reaches.

Acknowledgements

The research was conducted within the framework of the National Science Program "Information and Communication Technologies for a Digital Single Market in Science, Education and Security (ICTinSES)", funded by the Bulgarian Ministry of Education and Science.

References

1. Home Assistant. http://www.home-assistant.io
2. G. Kolev. Electrotechnica & Electronica, **56**, 2021, (accepted)
3. G. Kolev, E. Koleva. Proc. of 29th Int. Symposium "Management of Energy, Industrial and Ecological Systems", (*Bankya, Bulgaria*) 2021. (in Bulgarian)
4. G. Kolev, E. Koleva, L. Koleva. Science. Business. Society, **5** (3), p. 112-115, (2020)
5. Waze. https://www.waze.com/

Sterile Manufacturing Quality Control Methods in the Medical Products Industry

Toma Stulgė[1], Rūta Rimašauskienė[1*]
Kaunas University of Technology, Faculty of Mechanical Engineering and Design, Kaunas, Lithuania
toma.gagyte@ktu.edu, ruta.rimasauskiene@ktu.lt

Abstract: *Manufacturing of medical products is a very wide market. Many steps must be taken to ensure that produced product is sterile and safe and efficient to use for the customer. All manufacturing system from production floor to the type of sterilization must comply with required standards and regulatory. Every step of introducing new product to the production to routine production itself must be well documented and justified to be able to release the product to the market for human consumption. This paper presents information of production area requirements for medical devices, sterilization methods and sterilization indicators, briefly overlooks the quality control of such processes and the effectiveness of it.*
Keywords*: STERILE, MANUFACTURING, QUALITY CONTROL, MEDICAL PRODUCTS, STERILIZATION*

1. Introduction

The importance of quality control and inspection in manufacturing of sterile medical devices is exceptionally high. Stardartized procedures and quality control methods must be incorporated into routine production and followed strictly to ensure the best quality product will reach the customer and complaint level for the company will be as low as possible. Sterile medical devices should be sterile because these products are going to be infused directly into the bloodstream or body tissues [1].

Many steps must be taken to produce the sterile medical device. Starting from the qualified production area, validated and verified production processes, appropriate sterilization methods, succesfully passed audits and maintened required certification level. Many standards and requiraments must be fulfilled before succesfuly releasing the product to the market and, for example, ISO 13485 is one the most basic and most commom standard that medical devices manufacturer must follow. This standard basically specifies all requiraments for the Quality Management System for the manufacturer. The manufacturer of medical devices must demonstrate the ability to provide such medical devices and services that meets regulatory and customer requiraments. Besides compliance to ISO 13485, medical devices manufacturers has to comply with many more regulations and guidelines instituted by the FDA, ISPE, EMA, MHRA, and ICH, emphasizing good manufacturing practice and inspection requiraments in the manufacturing of medicinal products [2]. Sam A. Hout studies sterile manufacturing requiraments and fundamentals of aseptic techniques, quality by design, risk assesment, and management in support of sterile operations application [2] in the book "Sterile manufacturing. Regulations, processes, and guidelines".

Country/region	Standards/regulations	Conformity assessment
Australia	ISO13485 or EN46001[a] ISO13488 or EN46002[a]	Government and third party
Canada	ISO13485, ISO13488	Third party
European Union	EN46001[a] or ISO13485 EN46002[a] or ISO13488	Third party
Japan	GMP #40 ordinance GMPI #63 ordinance QS Standard for medical devices #1128 notice	Government
United States	QS (21 CFR part 820)	Government

Fig. 1 *Quality standards [3]*

The word "sterile" usually associates with the meaning that products or devices do not contain any viable pathogens, such as viruses, bacteria, fungi, and other living forms.

Neither visually nor by other means used nowadays, it is possible to quickly and without special research methods determine that one or another product is certainly "sterile". Nowadays, the term "sterile products" is understood to mean that these products or devices have been manufactured and prepared in appropriate ways, in accordance with strict rules and requirements. The necessary measures to ensure quality were used throughout the process, the process itself was controlled, and the results of the process and its control were documented. The concept also includes that the personnel involved in the processes have the necessary qualifications and are properly trained. The overall requirements for sterility are very nicely describe in Medical Device Directive 93/42/EEC points 8.3 – 8.7 and point 13.

The goal of sterile product is usually reached by sterilization or irradiation processes. Sterilization processes are carefully chosen for every type of the product or device as it can have a huge influence on product functionality and safety to the end user. These processes are expected to change used plastic [4], elastomer or other materials properties. Laurence W. McKeen investigates the effect of different sterilization methods on plastics and elastomers. Also, dozens of sterilization methods are reviewed in a very informative and simple way in the book "The Effect of Sterilization on Plastics and Elastomers" chapter 1. Medical devices manufacturers not only carefully choose the sterilization supplier, but also monitors closely the whole process. To ensure that sterilization process is completed successfully sterilization indicators are used widely across the industry. These indicators are used to identify that the procedure used for sterilization is completed and to avoid any confusion [5]. Shruti Moondra reviews the application of different types of sterilization indicators in the book "Sterilization of pharmaceuticals".

Cleanrooms and controlled production environment are a big part of medical devices, especially, sterile medical devices or pharmaceuticals production. The cleanroom environment has many potential sources of contamination, including: operators, equipment, structures, and any surface that can create particles via friction, heat, exhaust, outgassing, and static electricity charge [6]. During active production, millions of particles are generated into the environment. Associates that performs everyday activities in such production areas are considered to be one of the biggest contamination sources. This is the reason why the garment for operators and other personnel [6] must not be comfortable to work, but also be validated and monitored closely. Shih-Cheng Hu and Angus Shiue investigates the importance of validation, testing, penetration and application of the personnel factor for the garment used cleanrooms [6].

In this paper, production area requirements will be reviewed, as also the types of sterilization methods and indicators types. The quality control and effectiveness of sterilization process will be briefly overlooked in chapters 3.1 and 3.2.

2. Production area of sterile medical devices

Sterile medical devices are usually produced in cleanrooms, where environment is controlled. The product itself is usually not sterile immediately after production, but the bioburden level on the surface of such kind devices is significantly lower in comparison with normal production. Cleanrooms are frequently used not only for medical devices or pharmaceuticals production, but also for electronic, micro schemes or anything else that require low viable and non-viable particles concentration in the air.

Air filtration and overpressure are used to lower the particle and microorganism concentration presence in the environment, where production process is ongoing. Overpressure prevents air ingress

into the cleanroom, in this way when personnel is entering the room the particles from the outside does not flow into the room. The air is supplied through HEPA filters and high number of air changes per hour is kept. The biggest contamination in cleanrooms is considered to be people and materials as, in example, skin of a human sheds according the speed of its movement (Fig. 2).



Fig. 2 *Contamination from people [7]*

In the companies where cleanrooms are in operation special procedures are usually in place. Most manufacturers have established cleaning and disinfection procedures, gowning and behavior procedures, environmental monitoring programs, special personnel training programs, pressure monitoring instructions. For cleaning such production areas only approved and appropriate cleaning agents must be used, alternating them between to reduce the risk to develop bacterial resistance. The process of the cleaning must be validated to ensure its effectiveness.

Cleanrooms itself are classified into classes according the airborne particulate cleanliness per ISO 14644-1 standard (Fig. 3)

Table 1 — Selected airborne particulate cleanliness classes for cleanrooms and clean zones

ISO classification number (*N*)	Maximum concentration limits (particles/m³ of air) for particles equal to and larger than the considered sizes shown below (concentration limits are calculated in accordance with equation (1) in 3.2)					
	0,1 µm	0,2 µm	0,3 µm	0,5 µm	1 µm	5 µm
ISO Class 1	10	2				
ISO Class 2	100	24	10	4		
ISO Class 3	1 000	237	102	35	8	
ISO Class 4	10 000	2 370	1 020	352	83	
ISO Class 5	100 000	23 700	10 200	3 520	832	29
ISO Class 6	1 000 000	237 000	102 000	35 200	8 320	293
ISO Class 7				352 000	83 200	2 930
ISO Class 8				3 520 000	832 000	29 300
ISO Class 9				35 200 000	8 320 000	293 000

NOTE Uncertainties related to the measurement process require that concentration data with no more than three significant figures be used in determining the classification level

Fig. 3 *Cleanroom classification [8]*

Before starting normal production, such area must be validated and regularly re-qualificated. Cleanrooms that is classified as 5 class or higher must be re-qualificated to demonstrate compliance with particle concentration limits every 6 months as the lower classes every 12 months. Routine environmental monitoring should be completed to define the limit values for alert and action limits. During such monitoring the room is usually at operation conditions and it must be documented what type of products were produced during testing, number of operating machines and personnel in the room. Microbiological analysis of such monitoring and identification of microorganisms can reveal the true origin of the contamination (air, material, water or people). Different sampling methods can be used to determine the contamination (Fig. 4).

Active air sampling	Passive air sampling (settle plates)	Surface sampling	Hand sampling	Garment sampling
Production, at operation, before starting the production	Indicate particles contamination on the product	Production – NOT on critical points within machine operation	Any time, after sampling disinfection!	Always before the texile garments are changed – before being washed
Dressing room – right after change, when no people are present	Dressing room – during the change	Dressing room – contact plates at/after change, different sampling points	Swabs or contact plates, gloves print	Swabs or contact plates - hands, armpit

AIR: passive or active sampling
PEOPLE: hand swabs, contact plates, clothes
SURFACES: surface swabs, contact plates (RODAC)

Materials & Products: bioburden acc. to documented control plan

Fig. 4 *Sampling methods*

3. Sterilization methods and indicators

Many medical devices and products require sterilization to ensure that they are effective and safe for customer use. Sterility is therefore a critical quality attribute and is essential [9] for these products. Medical device only can be sterile or non-sterile, no partial sterility is impossible. Sterilization of medical devices and products is performed in several different techniques. Nowadays mostly used techniques are these:

- Saturated water vapor sterilization;
- Sterilization with Ethylene Oxide (E.O.) gas;
- Sterilization with low temperature steam and formaldehyde;
- Sterilization with hydrogen peroxide plasma;
- Gamma sterilization;
- Sterilization with dry hot air.

For the control of effectiveness of these sterilization techniques indicators are most widely used. To date, there is no universal indicator of sterilization, which could provide control of the sterilization effectiveness for all types of equipment [10]. Those indicators could be chemical, biological or different data loggers.

The evaluation of chemical indicators (CI) is based on clearly visible discoloration/change of colour after the sterilization cycle is over. But the chemical indicator's colour change only shows that the conditions where CI was positioned were what the indicator was designed to indicate. Therefore, only part of CI are used to evaluate the sterilization process. The possibility of correctly evaluating the effectiveness of sterilization depends on proper selection of indicators and the interpretation of their readings. Unfortunately, none CI could show whether the sterilization was truly effective.

Biological indicators (BI) are the only indicators that provide reliable assessment of the efficiency of the sterilization process. They consist of a culture of bacteria that are highly resistant to the sterilization conditions under particular study. Different BI with different cultures of bacteria is used for every sterilization technique. To acknowledge that sterilized device or product is suitable for use after the sterilization process where BI were used could only be done after the results of BI evaluation have been received. The process of evaluating the readings of BI could take up to 48 – 72 hours.

Data loggers, digital devices that record the physical data of the sterilization process, on the other hand, are relatively new way to control and evaluate the sterilization process. Firstly, the recording of process data (parametric control), was introduced in the industry. Unlike chemical indicators or biological indicators, parametric control provides much more information about the course of the cycle, the sterilization conditions achieved and the duration of the cycle. These loggers can also provide (and provides) information about preparation for sterilization, such as removal of air from the chamber, duration and number of preparation stages for sterilization, etc.. The application of the method in industry has

brought tangible benefits to consumers and significantly increased reliability of sterilized products. After starting using this control technique manufacturers have reduced the risk of placing improperly sterilized products on the market and dispensed the huge quantities of CIs used so far. The application of parametric control resulted in lower product costs and cost to consumers.

3.1. Sterilization process quality control

Quality control methods calls for effective inspection procedures, but product testing may not always be adequate [11] for sterilization process control. The variation of the sterilized product testing methods brings the uncertainty while evaluating results. The most used classical methods of microbiological testing as quality control for sterilized products or devices may not always be the most suitable choice. Results of microbiological testing may show the capabilities of laboratory, its personnel and procedures than sterilization effectiveness itself. For radiation sterilization (gamma sterilization, e-beam sterilization) simple dosimetry may be the key. Since standardized dosimetry is fairly simple, reliable, and reproducible, there is a trend towards using this method for assuring safe product release [11]. In Fig. 5 number of the applications of irradiation dosimetry can be seen.

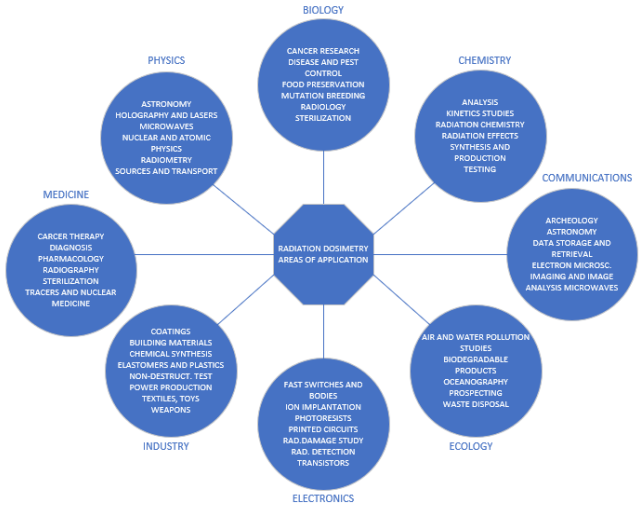


Fig. 5 *Dosimetry areas of application [11]*

The focus on quality control in producing the sterile medical devices can not be only based on QC in sterilization facility, it should be more of a system. The emphasis on quality control only in radiation processing without harmonization it with the other parts of the whole process of manufacture of a final product may not allow a final product to have been of required quality as a whole [12]. Manufacturers usually emphasize validation processes to choose the right type of sterilization and accurate dose, suitable materials of the device.

3.2. Effectiveness of sterilization

When radiation sterilization method is used to maintain sterilization process effectiveness usually dose audits are completed. The frequency of dose audits depends on many factors. In example, average bioburden level, equipment re-calibrations, maintenance of production equipment, change controls of the processes. When larger time interval is defined, proof and strong justification is required.

Bioburden

CFU / device	Method of dose determination	Max. interval dose-audit
≥ 1.5	Any	Quarterly
<1.5	Method 2 or VD max25	Quarterly
< 1.5	Method 1 or VD max15	Monthly
Any	Individual LOT release	Every individual LOT

Fig. 6 *Maintenance of radiation sterilization effectiveness based on bioburden*

ETO sterilization process effectiveness can be maintained by periodic control, justified regular and defined requalification of sterilization process, equivalence assessment. Medical devices that is sterilized by ethylene oxide sterilization method is marked very clearly. Special standards for this method are applicable because ETO is cancerogenic, mutagenic and reproductive toxic. Residuals after this sterilization can cause irritation of skin, eyes, blisters, burns and mutagenic – chromosomal defects.

There is a lot of factors when choosing the right type of sterilization for produce divice, but the comparison between most commom sterilization methods can be seen in Fig. 7.

Characteristic	Irradiation	Ethylene oxide	Steam
Efficiency	Excellent	Excellent	Excellent
Material compatibility	Majority of materials, some are decoloured, becomes brittle, are degraded	Majority of materials, not suitable for non-porous materials, liquids	Some materials, not suitable for temperature sensitive
Mechanism of action	Ionisation, damages in the DNA structure	Alcylation, damages in the DNA structure	Denaturation of proteins
Post-process control	Dose release, parametric	Biological indicators, parametric release	Biological indicators, parametric release
Quarantene	No quarantene (or 2-7 days)	2-7 days, until noEtO residuals are left	No quarantene (or 2-7 days)
Economical aspect	Very good for large and small volumes, high investment	Very good, small investment	Very good, the smallest investment

Fig. 7 *Comparison of the most frequent sterilization methods*

After sterilization medical device or product must be labeled accordingly the sterilization method used (Fig. 8)

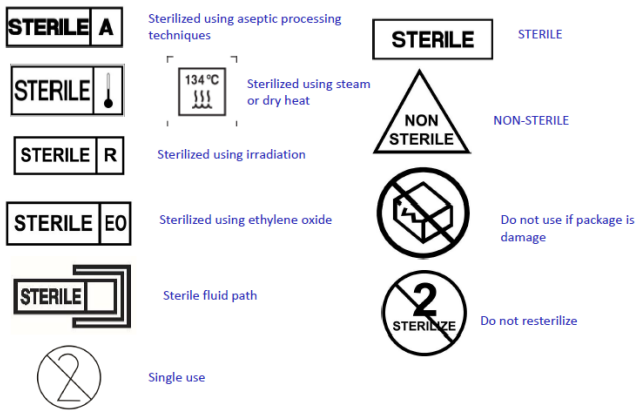


Fig. 8 *Labeling of sterile medical device*

Although, most manufacturers ships already finished product/device to sterilization facility, and it is already labelled as sterile even though it is non-sterile. Some specific restrictions and agreements are used in these situations, and some manufacturers

usually considers to have additional visual indicator on the package so the end user would sure, that the product is sterile.

4. Conclusions

Manufacturing sterile medical devices is strictly regulated by dozens of standards and guidelines instituted by various organization across the world. Various types of sterilization and irradiation methods may be used to sterilize the final product. The method may be chosen carefully according to the use of the product, raw materials that is used to manufacture it and most importantly end user. Different types of indicators could be used throughout the process to assure successful completion. Quality control of the sterilization process must be harmonized with QC in manufacturers facility to ensure the best quality products reaches the customers.

Acknowledgements

Research was funded by a grant (No. S-M-ERA.NET-20-1) (project: “Additive Manufactured Composite Smart Structures with Embedded Fibre Bragg Grating Sensors”, acronym: “AMCSS”) from the Research Council of Lithuania

4. References

1. Manmohan Singhal, MD. Habban Akhter, Devesh Kapoor, Lakshmi Kanta Kanthal, Yashu Chourasiya, Rahul Maheshwari, Anil Pethe, Rakesh K. Tekade. Advancements in sterile products and admixtures. The Future of Pharmaceutical Product Development and Research. Academic Press (2020)
2. Sam A. Hout, Sterile manufacturing. Regulations, processes, and guidelines (2021)
3. M. Gudeppu, S. Sawant, C. G. Chockalingam, & P.S. Timiri Shanmugam. Medical device regulations. Trends in Development of Medical Devices (2020)
4. Laurence W. McKeen, The Effect of Sterilization on Plastics and Elastomers (2018)
5. Moondra, Shruti. Dosage Form Design Parameters. Sterilization of Pharmaceuticals Technology, Equipment, and Validation (2018)
6. Hu, Shih-Cheng; Shiue, Angus. Validation and application of the personnel factor for the garment used in cleanrooms, Building and Environment (2016)
7. https://www.pharmamicroresources.com/2018/02/distribution-of-particles-within.html
8. https://www.pharmaguideline.com/2012/07/overview-of-iso-14644-clean-room.html
9. Fatima Hasanain, Katharina Guenther, Wayne M. Mullett and Emily Craven. Gamma Sterilization of Pharmaceuticals. A Review of the Irradiation of Excipients, Active Pharmaceutical Ingredients, and Final Drug Product Formulations. *PDA Journal of Pharmaceutical Science and Technology* March, 68 (2) 113-137 (2014).
10. Novikova Ye, Indicators of sterilization of medical products. National University of Pharmacy (2020)
11. William L. McLaughlin, Radiation measurements and quality control. , 9(1-3), 147–181 (1977)
12. V. N. Ponomarev, A. A. Molin, V. V. Kalashnikov, Ju. A. Drabkin. QC/QA system in radiation sterilization process on E-Beam irradiation plant, Department of radiation technologies of state research center (2006)

Aequor Tracer: Traffic Analyzer for GPON Networks

Lukas Jabloncik[1,*], Petr Munster[1], Tomas Horvath[1], and Vaclav Oujezsky[1]
Faculty of Electrical Engineering – Brno University of Technology, the Czech Republic[1]
Lukas.Jabloncik@vut.cz

Abstract: *For many years, passive optical networks (PONs) have received a considerable amount of attraction regarding their potential for providing broadband connectivity for every user: from the customer's point of view. However, Internet services providers (ISPs) must rely on producers of technologies to secure data. This article proposes additional opportunities to ensure data protection. PONs use their encapsulation method in optical domain transmissions. That is why it is necessary to solve security questions before optical line termination (OLT). When data are forwarded from the optical to the electrical domain, it is possible to evaluate time with dedicated hardware for optical networks. Own developed system can provide the following features: location of Internet protocol (IP) address, anomaly detection in traffic, ransomware detection based on similar behavior during data transmission, testing of defined address, usage of maps with defined IP ranges, providing all information on independent hardware via web page.*
Keywords*: PASSIVE OPTICAL NETWORKS, IP NETWORKS, CLUSTERING ALGORITHMS, INFORMATION SECURITY*

1. Introduction

Nowadays, the world is increasingly facing many types of cyber-attacks [1]. Attackers usually use malicious software to gain data and access to clients' computers. One of the malicious codes is the so-called Ransomware. It typically generates cyclically repetitive communication with command and control points or non-existent domains. This behavior can cause an anomaly that can be observed and analyzed.

Aequor Tracer (AT) software and hardware were designed for this monitoring and analysis. The solution is based on the Internet Information Services (IIS) which is running on a server. The two basic functions of the program are:

- Internet Protocol (IP) address position decision and localization.

- Behavior analysis of traffic and detecting any anomalies.

Other AT features include a Domain Name System (DNS) resolver, network tools, and traffic graphs. The presented solution also includes a custom-created set of base maps used for geolocation. The diagram in Fig. 1 shows the connection of the AT devices to the network. Traffic between the switch and the OLT is captured and mirrored to the AT device.

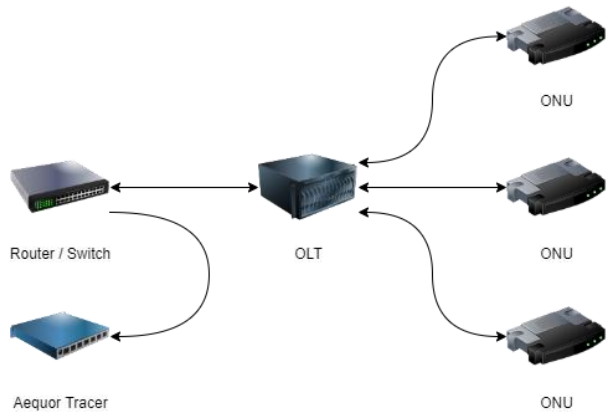


Fig. 1 *Aequor Tracer connection.*

The software is optimized for operation on low-power PCs. One of the conditions is the possible transfer of the test equipment. The prototype was built from the described software and hardware with the signaling elements. The elements signal the occurrence of an alarm.

In parallel with the development of the AT, the PON systems were tested for the presence of unsolicited traffic in a connection without direct access to the Internet. Passive research revealed the security risk of the Optical Network Unit (ONU). This was when using Common Gateway Interface (CGI) scripts. The risk allows receiving a response to such requests without the need to authenticate the user. An unauthorized person can thus gain access to a range of user configuration information. During an active survey, a network scan was performed by the Network Mapper (Nmap) tool [2]. Several open ports were detected. An example is the open Transmission Control Protocol (TCP) port 8023. This port could be the target of a possible attack. An inspection of the traffic with this target port was performed using the Endace probe. No activity was observed. However, the port does provide an opportunity for an attacker to perform a SYN flood Denial of Service (DoS) attack. The aim of this attack is to flood the drive with many TCP segments with the SYN flag set. In this situation, the system is unable to respond to other legitimate queries. This information helped in the development and testing of AT.

2. Threat assessment principle

Internet Protocol (IP) address positioning and localization

The developed algorithms integrated into AT for IP address location detection detect whether a particular IP address lies within the selected map. The algorithm makes a decision based on the detected latitude and longitude values. These values are used both for the IP address and form the background boundaries of each map.

Two methods, clustering and intersection, were tested for the calculation. In the clustering method, the K-Means algorithm and the intersection algorithm were chosen. The distance values within the cluster of the map without IP address and with IP address were compared in the clustering algorithm. This was used to determine whether a given point lies in the map. This algorithm was unsuccessful when the points lay close to the map boundary. In contrast, the algorithm based on the crossover method proved to be accurate even for points lying close to the map boundary. To prevent the degradation point, the verification of the starting point was implemented. This verification is because the boundary is also considered as part of the map. Therefore, we chose the polygon intersection algorithm for the implementation. The analysis can be done manually in AT by entering any IP address, or automatically for all new incoming IP addresses [1].

Analysis of traffic behavior and detection of possible anomalies

Traffic behavior analysis was primarily developed to detect the same or similar data behavior [3]. For example, to detect the activity of "ransomware" code which has regular characteristics when linking to control servers. Such analysis is possible for all traffic, regardless of time range and different tools. Consequently, it has been shown that any type of traffic has its characteristic trajectory at a particular viewpoint and time. This feature has therefore been included in this application.

It is possible to track sources that have identical properties. These sources are shown in the dependency graph. To do this, the lifelines algorithm is used. The converted lifelines are compared using the K-Means clustering algorithm to determine their similarity. Lifelines that are close to each other are grouped in a common cluster. These are evaluated as anomalies. Each lifeline

contains the same number of points in the same period. Because K-Means uses a fixed number of clusters, the current version of the application uses the following rule for the number of clusters. The total number of unique IP address occurrences is divided by two. Thus, if the lines are identical, they are assigned to the same cluster [4].

3. Software Aequor Tracer

The software is written in Python and uses open source libraries. Flask is used as a web framework. It is a microframework for Python-based applications with Werkzeug and Jinja 2. It is a Berkeley Software Distribution (BSD) license. AT can be deployed on both Windows and Linux operating systems using IIS or Apache, or run standalone without a support service for self-testing the application. The current solution uses Python packages and third-party code components. The entire solution is distributed under the Massachusetts Institute of Technology (MIT) license [4].

Description of program blocks

A simplified diagram of the AT is shown in Fig. 2. The AT is assembled from a front-end and a back-end. This allows users to use the functionality independently of the data updates during NetFlow or packet capture (PCAP) analysis that AT provides.

The back-end is the core Flask application that includes the background tasks of the Flask socket.io.One task starts the NetFlow analyzer and the same task starts the socket that listens for incoming NetFlow messages. The other task starts with the PCAP analyzer. When the data are received, it is stored in the internal database and the Flask socket sends a message to the front-end. The front-end application is also a Flask application. It uses @socketio.on to listen to incoming messages from the back-end. Receipt of the message means that the database has been updated with new data. Then processing functions such as survival function, clustering function, data generation function for graphs are started. These functions and algorithms have been described in the previous text. Then the data are uploaded to the graphical user interface (GUI) using socketio.emit. In the GUI, data and messages are processed using the _index.on JavaScript socket library.

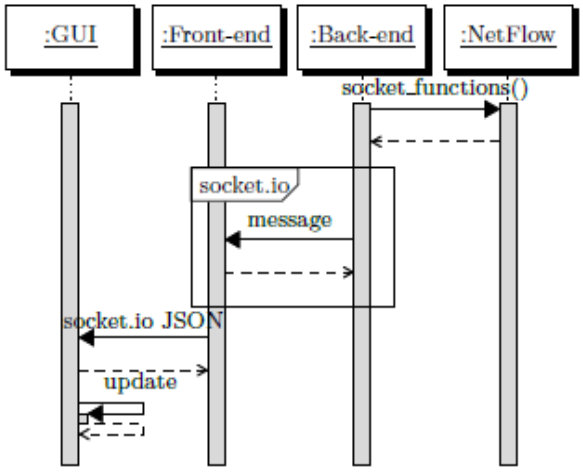


Fig. 2 *Simplified diagram of the AT.*

Modified queries

Modified queries consist of Python scripts that are designed to test the selected IP address. Only private addresses are selected. The principle is that when a private IP address arrives, the address is tested based on the profile chosen for testing. A profile is a set of tests that can be selected in the configuration. These sets are based on the testing performed on the project [5].

Map sources

The JavaScript Object Notation (GeoJSON) format is used to implement the maps. It is a standard defined by RFC (Request for Comments) 7946 [6]. It supports geometry types such as Point, LineString, Polygon, MultiPoint, MultiLineString, and MultiPolygon. Geometry objects with additional properties are Feature objects. FeatureCollection objects contain feature sets. It is possible to use and load a custom map in a defined format or select our predefined map data. This option is shown in Fig. 3. We have created a map package that contains almost all countries.

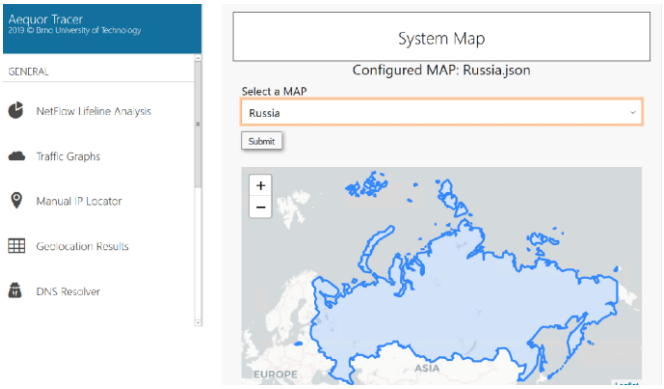


Fig. 3 *Map selector in the app*

AT interface for communication and data acquisition

The core consists of another software. It is a "socket listener". The software is created to establish a connection with the device. One part of it is a script using the SocketThread(Thread) function. It can therefore be used to establish a connection to any device, which, once the connection is established, will send a PCAP file continuously or in batches. Any PCAP file can be inserted into the application to serve as a source of traffic information. The PCAP file is read by the application using a Python script.

AT graphical interface

For easier work and control, the front-end of the application is created in a web environment. This is a modern trend that brings many advantages. Fig. 4 shows the main page of the application, which is the so-called "dashboard" for administrators. In the individual tabs of the application, there are additional components for configuration, control, and testing.

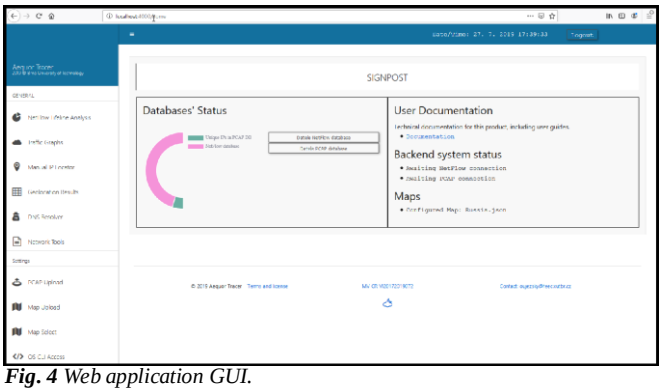


Fig. 4 *Web application GUI.*

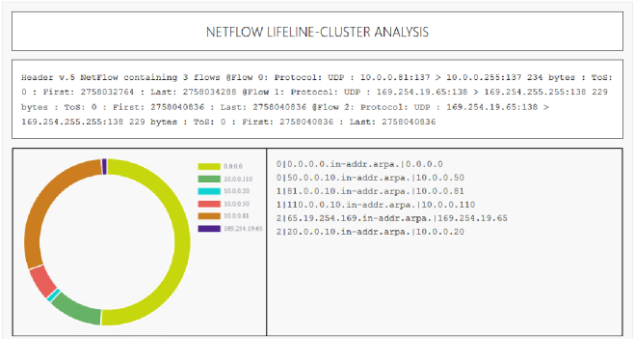


Fig. 5 *NetFlow Lifeline-cluster analysis.*

AT displays both the current data flows and the number of messages for a given IP, see Fig. 5.

Another graphical representation is the sigma chart in Fig. 6. The chart is created using the sigma JavaScript library [7]. In this graph, individual IP addresses are shown with dependencies on other IP addresses because they belong to a traffic similarity cluster. This view is useful for quick reference. For example, if a botnet attacked different sources and generated periodic traffic at different time intervals to connect to control servers, this cycle can be discovered.

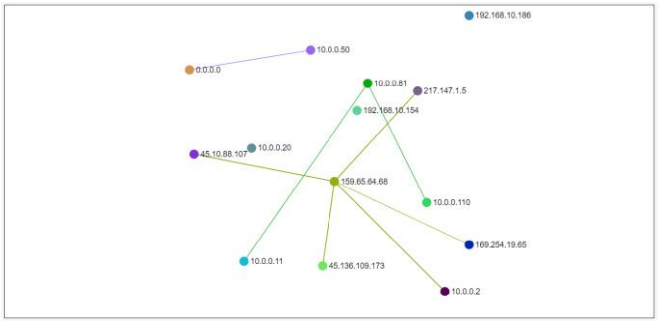


Fig. 6 *Sigma chart.*

It is also possible to graphically represent and download the result of the localization analysis in the Excel Binary File Format (XLS), see Fig 7.

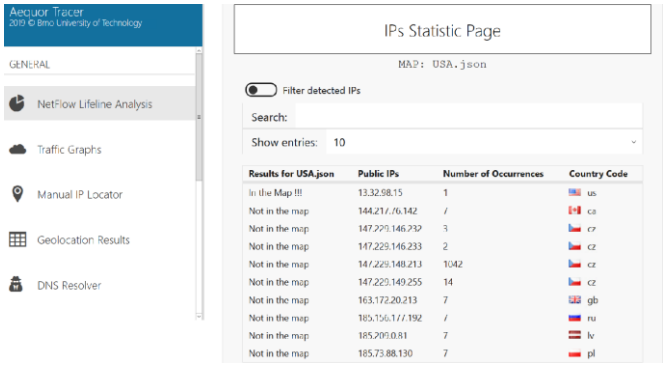


Fig. 7 *Summary of the analysis.*

4. Conclusion

The article described Aequor Tracer software for detecting cyber attacks in GPON networks. The article presents two basic functions of the software: "Internet Protocol (IP) address location decision and localization" and "traffic behavior analysis and detection of possible anomalies." Furthermore, the graphical environment of the program and its basic operation are described. The program is designed for low-power computers, is fully portable and is based on open source technologies.

Funding

Research described in this paper was financed by the grant of the Ministry of the Interior of the Czech Republic, Program of Security Research, VI20172019072, PID VI2VS/428 "Detection of security threats on the active components of critical infrastructures" and FEKT-S-20-6312.

5. References

1. V. Oujezsky, T. Horvath, P. Munster, *"Application for Determining whether IP Addresses belong to a Map by Coordinates"* 2019 42nd International Conference on Telecommunications and Signal Processing (TSP), doi: 10.1109/TSP.2019.8769100
2. G. F. Lyon, *"Nmap network scanning: official Nmap project guide to network discovery and security scanning"* 2008 Sunnyvale, CA: Insecure.Com, ISBN 0979958717.
3. V. Oujezsky, T. Horvath, V. Skorpil, "*Modeling botnet C&C traffic lifespans from NetFlow using survival analysis"* 2016 39th International Conference on Telecommunications and Signal Processing (TSP) , doi: 10.1109/TSP.2016.7760827
4. V. Oujezsky, T. Horvath, *"T. Traffic Similarity Observation Using a Genetic Algorithm and Clustering"* Technologies 2018, 6, 103. https://doi.org/10.3390/technologies6040103
5. V. Oujezsky, D. Chapcak T. Horvath, P. Munster, *"Security Testing Of Active Optical Network Devices"* 2019 42nd International Conference on Telecommunications and Signal Processing (TSP), doi: 10.1109/TSP.2019.8768811
6. The GeoJSON Format (RFC 7946) 2016, Internet Engineering Task Force (IETF), https://geojson.org/
7. A. Jacomy, "Sigma.js open-source JavaScript library" 2021, Github, https://github.com/jacomyal

Capability of micro-milling in machining of difficult-to-cut materials

Branislav Sredanovic[1,*], Djordje Cica[1], Stevo Borojevic[1], Sasa Tesic[1], Davorin Kramar[2]
University of Banjaluka, Faculty of Mechanical Engineering, Banja Luka, Bosnia and Herzegovina[1]
University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia[2]
branislav.sredanovic@mf.unibl.org

Abstract: *The trend of using micro-parts in modern industry puts new tasks for contemporary production technologies. If these parts are made of difficult-to-machine materials, machining problems become more complicated. On the other hand, the requirements go towards manageable and stable production processes, reduction of the processes number, reduction of the machining cost, using of clean technologies, etc. Use of mechanical solid tools in engineering materials micro-machining, many problems occur, such as: high machined surface roughness of the, tool deflection, intensive tool wear, etc. These problems lead to difficulties in establishing adequate process models, and thus the ability to control of micro-milling process and it's including in smart processes and smart factory concepts. This paper presents the possibilities of using micro-milling in the difficult-to-process materials machining. The phenomena in micro-cutting are analysed, as well as the output machinability indicators (surface roughness, tool wear, etc.). As a conclusion, guidelines and technological frameworks for the application of micro-milling in practice are given.*
Keywords*: MICRO-MILLING, DIFICULT-TO-CUT MATERIALS, ANALYSIS, MACHINABILITY*

1. Introduction

The contemporary development of industry, in accordance with the Industry 4.0 guidance, leads to the neediness for miniature parts and assemblies developing. Miniature assemblies and parts can be found in many branches of industry (gear systems, micro-actuators, micro-combustion device, micro-robots, micro-tools, mechanical components of sensors, components of measuring devices, etc.), but medicine also (micro medical devices, surgical tools, lenses, etc.). Such a wide range of different miniature products creates a huge market value, with a value of several billion dollars per year, and with constant growth [1, 2]. Like all other fields of industry, micro-production is on global market competition that results on strong demands to the production cost reducing. Also, the micro-parts industry is pressed by global guidance to reducing pollution and production waste, the using of renewable resources, etc. Any further development of this type of products and industry, must be within the sustainable production framework [3].

The micro-part is defined as part that has two perpendicular dimensions under 1 mm [4]. The main initiators of micro-parts development and productions are the automotive, military and aerospace industry, medicine, and energy sector. These industries are not focused on producing of micro-parts only, but also on producing of micro geometric shapes on macro-parts (Fig. 1). A wide range of different micro-parts, has conditioned the use of a wide range of engineering materials, such as: metals, glass, plastics, composites, special materials, etc. In micro-technologies, in addition to the general micro-part materials properties, other properties become important, such as: properties of each type of materials structure grain, properties of structure grain borders, elasticity, electrical conductivity, magnetism, tendency of surface layers to adhesion, surface reflectivity, etc. There are very complex processes and phenomena that weren't characteristic and significant in machining processes on macro-level. All of the above points to complex micro-level industry processes on: construction, machining, measurement and manipulation.

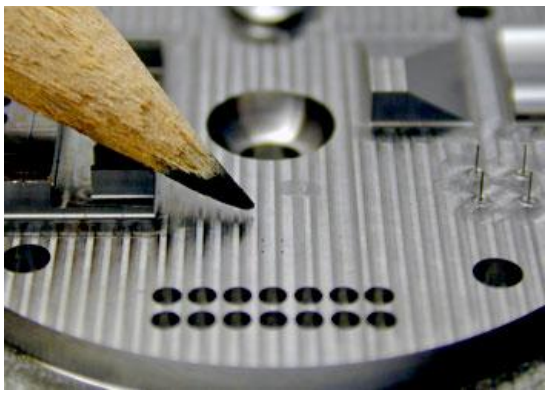


Fig. 1 *Micro-forms on metallic part [5]*

In this paper, the possibility of using solid tool processes in the machining of micro-parts functional surfaces is presented. Focus of analysing is machining of difficult-to-cut materials. In next, micro-production technologies were qualified, basic process phenomena were described, the advantages and disadvantages are listed. On next, analysis of experimental measurements was performed. The aim of the paper is to create the basis guidance for micro-machining process modelling, for the purpose of machining process adequate control and monitoring. It should be noted that micro-machining processes are advanced processes, which are part of Industry 4.0. However, all mentioned is prerequisite for incorporating and using these technologies into the smart factory framework, which is derived from Industry 4.0 concept.

2. Micro-machining technologies

Micro-production technologies can be divided in two groups: micro-system technologies (MST) and micro-engineering technologies (MET) [6]. The first one is focused on productions of micro-electro-mechanical systems (MEMS), on example: computer components, sensors, electronic devices, etc. There are production processes based on etching, electronic and ion beam machining, photolithography, etc. The micro-engineering technologies are focused on production of mechanic micro-parts or micro-forms, such are: micro-surfaces, micro-holes, micro-channels, micro-shafts, micro-gears, micro-chambers, micro-valves, etc. The production processes of mentioned micro-parts can be based on: additive processes (micro-casting, and 3D printing processes), thermal processes (electro-discharge machining, laser beam machining, etc.), or mechanical processes (micro-cutting, micro-forming, non-conventional micro-machining). Subgroup of micro-cutting processes include: micro-turning, micro-drilling, micro-milling, and micro-grinding (Fig. 2).

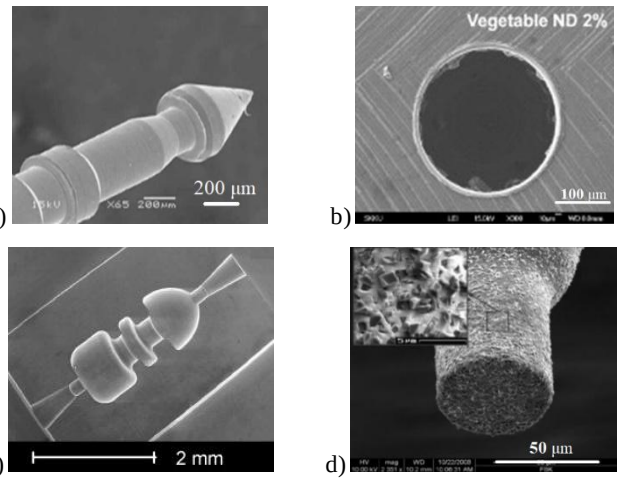


Fig. 2 *Micro-parts produced by mechanical micro-cutting: a) micro-turning, b) micro-drilling, c) micro-milling, and micro-grinding tools [7-10]*

3. Micro-milling of metallic materials

Generally, micro-cutting technologies are used for machining of functional surfaces on micro-parts or micro-forms. According to the type of workpiece material, micro-cutting processes are divided into two types: hard micro-machining (hardened steels, super alloys, glass, etc.) and soft micro-machining (aluminium, brass, plastic, graphite, etc.). As the cutting wedge penetrates in the workpiece material, complex processes occur in the chip forming zone, which are characteristic for micro-cutting. Unlike cutting process and chip forming of workpiece material at the macro level, in the cutting process and chip forming at the micro level, the relationship between geometric and process parameters has a great influence on output parameters and machinability indicators. This relations is described by "size effect" [3, 7]. The size effect is the situation when the rank values of geometric parameters, on example radius of cutting edge (r_c), or crystalline grain size (g_s); and the rank values of cutting process parameters, such are cutting thickness (h), are in the same value range.

Depending on the ratio of the mentioned values, some characteristic cases of workpiece material removing mechanism by cutting wedge, can be defined: a) plugging, b) plugging and cutting and c) dominant cutting (Fig. 3). Each of the material removing mechanism cases is not constant during the machining time. This is due to the cutting tool wedge wear, the change of cutting edge geometry, the workpiece material crystalline structure non-homogeneity, elastic and plastic deformation of workpiece material, dimensional deformation of cutting tool body, cutting process kinematics (on example in milling), etc.

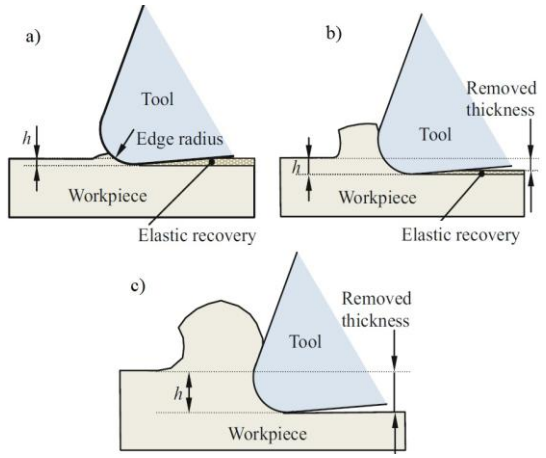


Fig. 3 *Material removing mechanisms n micro-cutting [11]*

In papers [1 - 5], investigation on solid-tool based machining of different metallic materials and machinability was given. Different authors analyzed various metal cutting processes and its possibilities in micro-part machining [7 - 10]. Also, influence of size effect on process performances was investigated by Bissasco et al [3], and Chae et al. [11]. Influence of cutting parameters, cutting tool coatings in micro-milling of Inconel 718 was investigated by Ucun et al. [12]. They concluded that specific coatings on cutting tool are given the best surface roughness. Experimental analysis of micro-milling of super-alloys Inconel 718 and Ti6Al4V, with 0.8 mm diameter flat-end milling tool, was performed by Kuram and Ozcelik [13]. Lu et al. [14] investigated residual stress on micro-parts surface. They performed analysis and comparison of simulated and experimental measured data, which given on micro-milling of Inconel 718. In study [15], Lu et al. investigated machined surface roughness consideration of cutting tool wear, during micro-milling of Inconel 718. There was investigated influence of cutting tool coatings on tool wear and surface roughness. Modelling of micro-milling process by FEM was performed by Thepsonthi and Ozel [16]. In this study, FEM model constants was adopted by micro-milling of Ti-6Al-4V alloy by cBN coated cutting tool. Influence of cutting parameters on process performances, in five-axis micro-milling and deep hole drilling in nickel-titanium alloys, was investigated by Biermann et al. [17]. During investigation of micro-milling process of Ti-6Al-4V, Jaffery et al. [18] are performed statistical analysis on influence of process parameters on machinability indicators. Krishnan and Mathew [19] performed studies on cutting tool wear in micro-milling of Inconel 718. There was investigated behavior of newest cutting tool coatings and its influence on cutting tool performance and machined surface roughness. Similar studies were performed by Atif et al. [20]. They investigated effect of cutting tool coatings and cutting parameters on part quality indicators.

Machining of complex geometry micro-parts made of difficult-to-machining materials (hardened tool steels, super alloy, etc.), leads to the complication of the micro-cutting process. There is an increase of the cutting forces value and deforming of milling tool, more generated heat and more intense abrasive and adhesive cutting edge wear, and etc. As mentioned earlier, micro-milling process are used to machining of functional complex surfaces on micro-parts. If difficult-to-cut workpiece materials are there, main problems is obtaining high shape accuracy, dimension accuracy, satisfactory machined surface roughness, but also a low machining cost. In order to build the efficient control and monitoring of the micro-milling process, it is necessary to perform an analysis of process capability. The aim is obtaining appropriate machinability indicators, and enable possibility of adequate cutting process output parameters modelling.

4. Experimental analysing and discussing

Experimental run were performed on three axis high speed micro-milling machining centre Sodick MC430L, which placed in Laboratory for cutting on FME Ljubljana (Fig. 4). As cutting tool was used flat end mill cutter SECO, TiAlN layer coated. Tool has diameter is 600 µm, corner radius 0.05 mm, and extra-long neck 8 mm. There is two flute, with maximum cutting depth of 0.8 mm, and helix revolution angle is 7.25°.



Fig. 4 *Micro-forms on metallic part [3]*

Experiment runs was performed in channel milling, with different milling process parameters. Workpiece was nickel-chromium super alloy Inconel 718 (53% Ni, 19% Cr, 18% Fe, 5.1% Nb, 3% Mo, 1.1% Ti, 1% Co, 0.5% Al, 0.35% Si and 0.08% C), with tensile strength 1350 MPa, and hardness 40 HRc. It used in responsible parts for mechanisms which work in extreme mechanical and thermal conditions, regard to excellent oxidation and high temperature resistance. During micro-milling of channels, MQL was used as lubrication technique. The channel depth corresponded to the depth of cutting. Experimental plan was adopted as full factorial plan, with two changeable milling parameters: depth of cutting a_p (mm), and feed per tooth f_z (mm/tooth), on three level each. It was given nine experimental runs with different parameter combinations without repeat. Cutting speed was constant v_c = 40 m/min, and width of milling a_e = 0.6 mm.

After each experimental run machined surface roughness at channel bottom was measured. Measuring of surface roughness was performed on Alicona Infinite Focus optical scanning device.

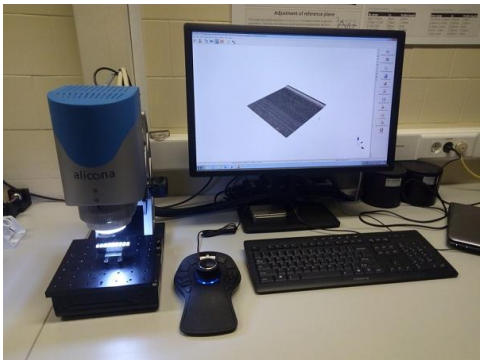


Fig. 5 *Surface scanning on Alicona optical measuring device*

Results of arithmetical mean height of surface roughness (R_a) for machining with different cutting parameters combination were shown on Fig. 6. The highest surface roughness, was on channel that machined with depth of cutting of 0.03 mm, and feed per tooth of 0.018 mm. As theoretical expected, minimal machined surface roughness was obtained when machining with minimum parameter values - depth of cutting of 0.01 mm and feed per tooth 0.008 mm. Observing the diagram and the values for some process parameters combination, it can be noticed that the increase of input process parameters is not accompanied by the increase of machined surface roughness values. This is more pronounced for lower process parameters values. As opposed to machining at the macro level, previous noted occurrence is due to the size effect. It occurred because the cutting process parameters values were close to the cutting tool radius. In that case, the workpiece material plunged with the cutting tool wedge. Also, there may be cases that the values of the parameters were close to the size of the crystal grains in the material of the workpiece, and material removal occurred at the structure grain boundaries.

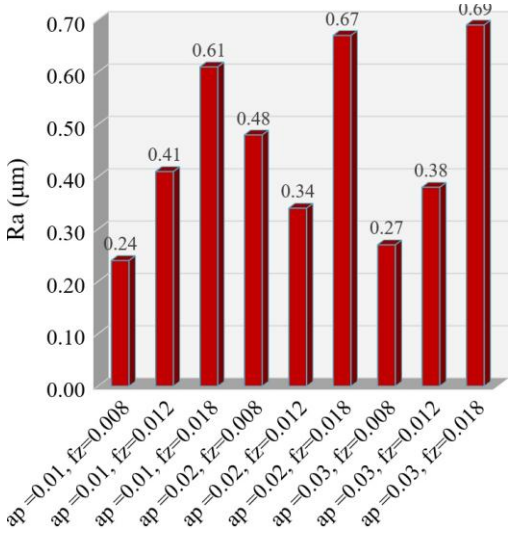


Fig. 6 *Surface roughness of micro-milled channel bottom [3]*

Based on the input cutting parameters and measured data, machined surface roughness modelling was performed. For it, Design Expert 7 software was used. For mathematical model formulation, based on RSM method, software was proposed 2FI (model with parameters interaction) versus Quadratic model. Based on statistical indicators, a modified model with one interaction and one square parameter was formed. The coefficients of the mathematical model were calculated using the least squares method. Statistical analysis was performed by ANOVA. Based on statistical parameters p-value and f-value, as significant parameters the feed per tooth was determined, while the depth was noted as less significant process parameter. Model mathematical formulation for prediction of arithmetical mean height of surface roughness is given as:

$$R_a = 0.546 + 1.333 \cdot a_p - 58.333 \cdot f_z + 3500 \cdot f_z^2 \quad (1)$$

Based on measured data and values calculated by mathematical formulation, statistical analysis was noted average values of 0.45, and standard deviation of 0.088. Model is significant, that noted by p-values is 0.023. Signal to noise ratio is 6.0, and regression coefficient R^2 is 0.83. Based on this, can be concluded that mathematical model for prediction of machined surface roughness is adequate at least. Based on it, RSM graph is formed, and showed on Fig. 7. Based on presented graph, can be concluded that machined surface roughness increases by exponent function with increasing of feed per tooth. Machined surface roughness increase by linear function with increasing of depth of cutting. From the graph shape it can be seen that the earlier explanations of the results variation on low range process parameters, partially included and observed by presented model only. For that reason, a slightly lower regression coefficient was obtained.

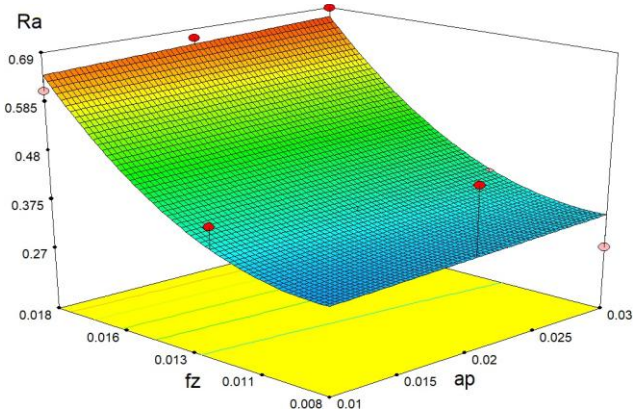


Fig. 7 *Surface roughness model response*

The machined surface roughness increases during machining time. The change of the machined surface roughness was measured at the beginning and at the end of the cutting tool wear monitoring. At the beginning of machining average surface roughness value was 0.34 µm, and at the end of the monitored machining time it was 0.49 µm. This is due to cutting tool wear, as a consequence of adhesion, diffusion and abrasion wear mechanisms. The cutting tool wear in micro-cutting of metals is intensive due to the pronounced size effect. Measuring of cutting tool was performed on Alicona Infinite Focus optical scanning device, also. Cutting tool wear is monitored via parameter, such as the cutting edge radius, because it is directly related to the appearance of the size effect (Fig. 8). Thus, the chip removal mechanism during machining time can be changed from chip separation to the plugging effect.

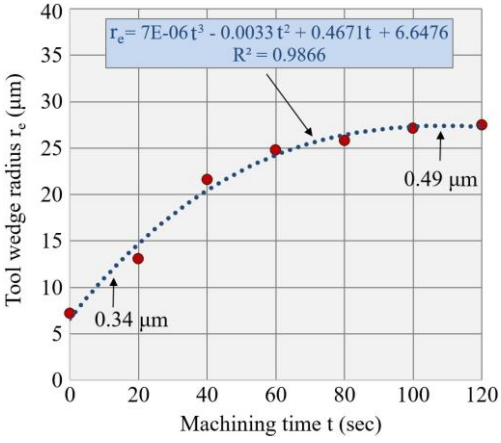


Fig. 8 *Increase of surface roughness during machining time*

5. Conclusions

This study presents the basics of micro-technologies used in the processing of metallic micro-parts. Based on of available literature sources, technologies and methods are classified, and their technological frameworks are summarized. In this paper, the main focus was on mechanical micro-cutting methods, due to the phenomena associated with the size effect, different chip removal mechanisms, and consequential problems in achieving the appropriate machined surface quality and dimensional in terms of economical machining process. Experimental analysis was performed on micro-milling of super-alloy Inconel 718, due its difficulties in machining, and as one of irreplaceable engineering material in modern constructions which exposed to extreme exploitation conditions. Experimental analysis included machined surface roughness measurement, analysis of measured data, and formation of the predictive model of the arithmetical mean height of surface roughness. In addition, there was monitored of surface roughness increasing during machining time due to cutting tool wear. A mathematical model was obtained, and statistical analysis using the ANOVA method and full factorial experimental plan was performed. On the other hand, a lack of formed mathematical model into describing of the arithmetical mean height of surface roughness value was noted. This changes in depending on some combinations of input parameters, which caused by size effect.

However, the obtained results and analysis indicate that micro-milling is one of the machining methods, which can gives the appropriate machined surface roughness on micro-parts made of Inconel 718. Future research will go in the direction of analysing the micro-machinability of other super-alloys. Artificial intelligence (AI) will be included in the micro-cutting process modelling, in line with the Smart factory framework and Industry 4.0 guidelines. Previous research has shown that AI modelling method can give much more accurate models and adequate describing of complex phenomena.

6. References

1. D. Dornfeld, S. Min, Y. Takeuchi: Recent advanced in mechanical micromachining, Annals of CIRP, **55 (2)**, 745-768 (2006).
2. M.A. Camara, J.C.C. Rubio, A.M. Abrao, J.P. Davim: State of the art on micromilling of materials, a review, J Mater Sci Technol **28 (8)**, 673–685 (2012).
3. G. Bissacco, H.N. Hansen, L. De Chiffre: Size effects on surface generation in micro milling of hardened tool steel. Annals of CIRP, **55 (1)**, 593-596 (2006).
4. F. Schneider, J. Das, B. Kirsch, et al.: Sustainability in ultraprecision and micro machining: a review, Int. J. of Precis. Eng. and Manuf. - Green Tech. **6**, 601–610 (2019).
5. "State of the art micromachining CNC service" by 3D Industries, Inc. Web site: https://3dind.com/micro-machining/. Accessed: 04.11.2021.
6. E. Brinksmeier, O. Riemer, R. Stern: Machining of precision parst and microstructures", *Proc. of 10th International Conference on Precision Engineering (ICPE)*, Yokohama, Japan, 3-12 (2001).
7. M. A. Rahman, M. Rahman, A. S. Kumar, H. S. Lim: CNC microturning: an application to miniaturization, Int J Mach Tools Manuf **45(6)**, 631-639 (2005).
8. J.S. Nam, P.H. Lee, S.W. Lee: Experimental characterization of micro-drilling process using nanofluid minimum quantity lubrication, Int J Mach Tools Manuf **51(7)**, 649-652 (2011).
9. C. Brecher, C. Wenzel, R. Klar: Characterization and optimization of the dynamic tool path of a highly dynamic micromilling machine, CIRP J Manuf Sci and Tech **1(2)**, 86-91, (2008).
10. J. C. Aurich, J. Engmann, G. M. Schueler, R. Haberland: Micro grinding tool for manufacture of complex structures in brittle materials, CIRP Annals - Manuf Tech **58(1)**, 311-314 (2009).
11. J. Chae, S. S. Park, T. Freiheit: Investigation of micro-cutting operations, Int J Mach Tools Manuf **46**, 313–332 (2006).
12. I. Ucun, K. Aslantas, B. Gockce, F. Bedir: Effect of tool coating materials on surface roughness in micromachining of Inconel 718 super alloy. P I Mech Eng B-J Eng **288(12)**: 1550-1562 (2014).
13. E. Kuram, B. Ozcelik: Optimization of machining parameters during micro-milling of Ti6Al4V titanium alloy and Inconel 718 materials using Taguchi method. Proc I MechE Part B: J Engineering Manufacture **231(2)**, 228–242 (2017).
14. X. Lu, Y. Lu, F. Wang, C. Zhao: Research on surface residual stress of micro-milling nickel-based superalloy Inconel 718. Int J Nanomanufacturing **12(1)**, 82 – 92 (2016).
15. X. Lu, Z. Jia, H. Wang, L. Si, X. Wang: Surface roughness prediction model of micro-milling Inconel 718 with consideration of tool wear. Int. J. of Nanomanufacturing **12(1)**, 93 - 108 (2016).
16. T. Thepsonthi, T. Ozel: Experimental and finite element simulation based investigations on micro-milling Ti-6Al-4V titanium alloy: Effects of cBN coating on tool wear, J Mater Process Tech **213**, 532– 542 (2013).
17. D. Biermann, F. Kahleyss F, E. Krebs E, T. Upmeier: A study on micro-machining technology for the machining of NiTi: five-axis micro-milling and micro deep-hole drilling, J Mater Eng Perform **20(4-5)**, 745-751 (2010).
18. S. H. I. Jaffery, M. Khan M, L. Ali, P. T. Mativenga: Statistical analysis of process parameters in micromachining of Ti-6Al-4V alloy, Proc IMechE Part B: J Eng Manuf **230(6)**, 1017–1034 (2016).
19. N. A. Krishnan, J. Mathew: Studies on wear behaviour of AlTiN-coated WC tool and machined surface quality in micro endmilling of Inconel 718. Int J Adv Manuf Technol **110**, 291–307 (2020).
20. M. Atif, M. K. Gupta, T. Mikołajczyk, D. Y. Pimenov, K. Giasin: Effect of tool coating and cutting parameters on surface roughness and burr formation during micromilling of Inconel 718, Metals **11(1)**, 1-18 (2021).

Acknowledgement

This paper is results of activities on interstate bilateral project, in cooperation between Department for management of production technologies at FME Ljubljana and Department for production and computer aided technologies at FME Banja Luka. The project is supported by ministries and governments of Republic of Slovenia and Republic of Srpska.

Technology for production of technical products with fixed thickness and made of quartz ceramics by means of a moulding matrix with a silicone insert

Gabriel Peev, Lyuben Lakov, Gergana Mutafchieva*, Mihaela Aleksandrova
Bulgarian Academy of Sciences, Institute of Metal Science, Equipment, and Technologies with Center for Hydro- and Aerodynamics "Acad. A. Balevski", cl.creativeline@gmail.com

Abstract: *Molding of technical products with fixed thickness by casting quartz ceramics, based on pure quartz glass, requires specific technological regulations both in the preparation of the ceramic mass and in the process of molding itself. Due to the specific characteristics of the colloidal system such as low shrinkage and viscosity, casting in molds made only of gypsum is practically unworkable. A solution lies in developing a technology in which the dismantling of the die is supported so that the molded product can be easily removed. Proposed here is a gypsum mold developed in such a way that a silicone insert is mounted where the lower part of the cast product will be. The technological process presented here in detail includes the main stages of preparing a model according to pre-set parameters, making a gypsum mold consisting of two-parts and with a silicone insert, casting and high-temperature synthesis of the finished product made of quartz ceramics. The development is suitable for complex and large-size technical products made not only of quartz ceramics, but also of other silicate colloidal systems characterized by low and almost zero air shrinkage.*
Keywords*: QUARTZ GLASS-CERAMICS, SILICONE MOULD, INOVATIVE QUARTZ CERAMIC'S MOULDING*

1. Introduction

The development refers to the moulding of technical products with fixed thickness, for which there exist specific requirements for thermal resistance. Presented below are all the stages of the whole technological process: development of constructive documentation for building a model, taking into account the shrinkage of the material; preparing the complete moulding equipment which consists of a gypsum mould and a silicone insert; moulding of the product; high-temperature synthesis and finally, obtaining a finished product. As an example, we present a product with thick walls and with a certain depth, shaped as a truncated quadrangular pyramid with external dimensions of 205 x 105 h x 75 mm and wall thickness of 16 mm. The product is a refractory container used in the synthesis and melting of high-temperature steels. Other suitable examples are the production of equipment for pouring receivers (cups and crucibles) for steel melts, as well as saggars for the synthesis of zirconium cermets. The ceramics from which these products are made must meet certain requirements such as resistance to high-temperature shock, refractoriness and resistance to aggressive metals. One of the best ceramics meeting the above requirements is quartz glass ceramics. The refractory vessel can be developed from two products – mullite quartz and quartz ceramics. In the present study we consider the technological process of casting the second product. The casting of products with a complex shape from pure quartz glass ceramics requires a precise and specific technological process for their preparation, depending on the indicators and characteristics of the used ceramic composition in a colloidal state. An aqueous colloidal system based on amorphous SiO_2 from ground quartz glass consisting of two fractions in a 1:1 ratio a) 0.3-0.15 mm and b) <125 μm is used. Homogenization and grinding is carried out by wet mixing in a mill unit (ball mill) by a single-stage technique in the conditions of an exothermic process, in which higher indicators of the final suspension are achieved. In the process of obtaining an aqueous colloidal system of quartz glass powders, the water exerts an active surface influence on the amorphous SiO_2 . In order to obtain a suspension with low humidity, an additional 5% of the powder mixture is added to the aqueous colloidal mixture 3–4 times before the final completion of the processes in the system, the process of stirring and final grinding taking approximately 2 hours. As a result of the water grinding of the quartz powders, a specific surface of 600–900 cm² per g is achieved. Initially, 25% distilled water is added to the system, and at the end of the process the amount of water is reduced to 22%. The duration of the water grinding before the additional activation with small portions of powder is 25–26 h. The resulting suspension quickly shapes the body of the raw product, and the products have a low shrinkage – up to 0.05%. The activation of the system is associated with the hydration of SiO_2 and the formation of surface tetrahedra due to the coupling of solid particles of SiO_2 with ionized silicic acid which is obtained in the process of the water grinding with water playing an active role. An important requirement in the preparation of the slip is to monitor the pH of the suspension, where the optimal pH value is 4.5. Adjustment of the pH is done using HCl for lowering and VH_4 OH for raising it. The high-temperature synthesis is performed at a temperature from 1,230°C to 1,260°C [1-2]. In the experimental part we present a modern technology for moulding ceramic products, whose mould includes a silicone insert in addition to the gypsum part. The approach is entirely innovative due to the specific behavior of the particular ceramic material in the process of slip casting, as the gypsum mould avoids absorbing the water contained in the material.

2. Experiments

The experimental part includes several main stages, starting with the preparation of instrumental equipment and ending with the moulding and high-temperature synthesis of technical products made of quartz glass ceramics. The first step in the preparation of the instrumental equipment is the compiling of technical documentation that specifies the entire set of the necessary parameters relating to products made of special ceramics. Figure 1 shows a cross section of the refractory vessel, subject to the present development, with specific parameters excluding compressibility.

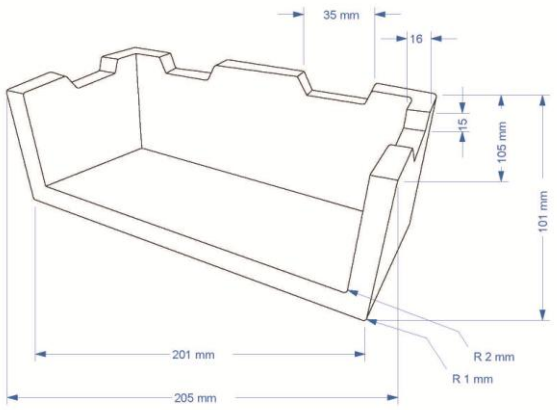


Fig. 1. *Cross section of a fixed-thickness refractory container for melting high-temperature steels. The set parameters refer to the finished product, to which should be added an increase relative to the mass used, which for quartz ceramics is 0.2%.*

After the requirements regarding the dimensions and the compressibility relative to the mass used are specified, the process of making the actual model with the necessary magnification is started. The next stage is preparing the moulding equipment – a gypsum mould with a silicone insert – which is the main tool in the moulding process. The material used for the model and the base of the casting mould is moulding gypsum, a hemihydrate with the chemical formula CaSO45H2O mixed during casting in a weight ratio of dry matter to water of 1:1.5 [3]. The silicone insert uses a

two-component elastomer ZA22 by the Italian company Zhermack, with polymerization at room temperature and a Shore A hardness of 22. The characteristics of the material depend on the properties of the product in the course of all processes after vulcanization [2]. Among the main properties of ZA22 are high chemical resistance to aggressive components; high tensile strength and high elasticity; high reproduction accuracy, listed in detail in Table 1 [6].

Table 1: *Chemical and physical properties of the silicone elastomer used in the making of the polymer insert in the casting mold.*

Mixing ratio	1 : 1
Viscosity of pre-catalyzation mixture	4000 ± 300 cP
Density of the Base component (g/cc)	1,13
Density of the Catalyst component (g/cc)	1,13
Colour	Blue
Working time at 23 °C (73 °F)	WT=14' – 17'
Setting time at 23 °C (73 °F)	ST= 60
Vulcanized product:	
Shore A hardness after 24 hours	21 ± 2 ShA
Breaking load	4.0±0.2 N/mm2
Elongation at break	380 ± 20 %
Tear strength	>20 N/mm
Reproduction of details	2 µm
Dimensional variation after 24 hours	< 0.05 %

An elastomer with suitable hardness was selected according to the Shore durometer, which refers to the stability of the polymers subjected to plastic deformation. The elastic performance of the silicone used allows flexible disassembly without tearing either the insert itself or the moulded product [4-5].

The making of a model depends on the shape and cross-section of the product as set in the drawing. In the case of the refractory container, the model is made by hand in several stages. Specific for products with a fixed thickness is that the model must match on its inside the shape of the finished product, as opposed to those with an arbitrary thickness. For this purpose, a negative auxiliary part is initially made, through which the core is formed. The auxiliary part is machined according to all the necessary slopes and set radii, so that after casting the base, no subsequent work on the inside of the model will be required. The outer contour with the set obligatory thickness (in this case 16 mm + 0.2% increase to take into account the shrinkage of material at high temperature) is enclosed around the core and prepared for casting. The model is given a final shape externally according to the slopes and the set radii, after which the casting mould can begin to be made.

The making of a two-part gypsum mould with a silicone insert begins with the first gypsum part, which forms the outer part of the product, and the sprues. The first part also serves as a base on which an auxiliary plate will be built together with the model. This plate will subsequently shape the silicone insert and determine its thickness according to the necessary technical parameters. It should be of equal thickness of approx. 7 mm, except for technological slopes for disassembly, so that the product can be removed without a problem. The second gypsum part occupies the space above the auxiliary base and it is a required mould thickness which is of approx. 35 - 40 mm for technical products. After the second part of the mould is ready, the auxiliary plate is removed and in its place is poured elastomer using the pourers additionally formed in it. It is desirable, after homogenizing the two components of the polymer, to perform a deaeration in a vacuum environment. The time required for complete vulcanization of the silicone is not longer than 24 hours, after which the material acquires all the necessary elasticity and strength. Figure 2 shows the parts of the mould die together with the silicone insert.

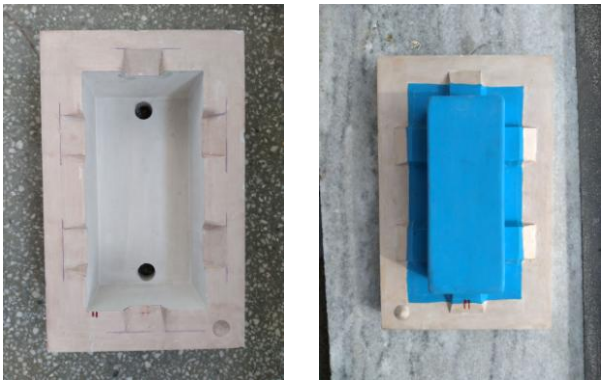


Fig. 2. *Two-part gypsum mould with silicone insert. The first part, together with the sprues, forms the outer shape of the moulded article, while the silicone insert forms the inside.*

3. Conclusion

A successful experiment was performed using an innovative approach for moulding a technical product with a fixed thickness made of quartz glass ceramics. The topical importance of the development is twofold. Firstly, it lies in the authors' original recipe composition of an aqueous colloidal system of ground quartz glass based on amorphous SiO_2 , which allows the finished products to meet the specific requirements for thermal stability at high temperature. The low shrinkage of 0.2% and the water saturation of the suspension of 22%, in turn, requires the development of a specific process to facilitate the moulding stage, which leads to the second main innovative feature – the development of a gypsum mould with a silicone insert. The use of elastomer for the moulding parts for casting ceramic products is not a common practice due to the high water content in the ceramic colloidal compositions and the requirements for water absorption by the matrix mould. The selected polymer meets the necessary conditions after its complete vulcanization and especially those for elasticity, due to the depth of the final product and the relatively small degree of internal slopes. Figure 3 shows the final result for three samples of a refractory container after high temperature synthesis at 1,250°C and retention at a final temperature for 60 minutes.

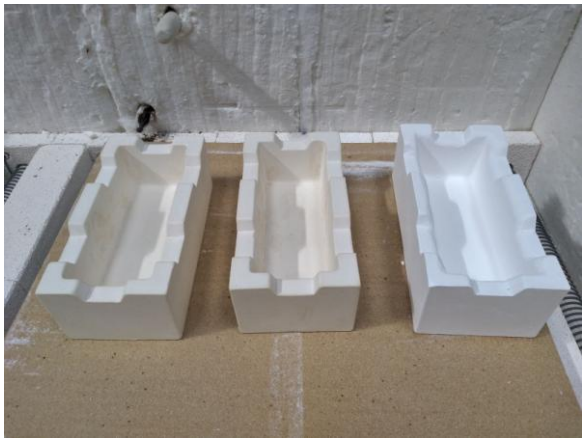


Fig. 3. *High temperature synthesis of technical products with fixed thickness – refractory containers made of quartz glass ceramics, moulded in a gypsum mould with a silicone insert.*

The experimental development shows the successful realization of thick-walled deep products made of special ceramics with low air shrinkage and moisture content of the initial mass. The study may be applicable to all similar masses meeting these requirements.

Acknowledgement

The authors are grateful to the financial support of the Bulgarian National Science Fund at the Ministry of Education and Science, Contract No КП-06-ОПР 03/4 14.12.2018, for carrying out the necessary research.

4. References

1. Gerasimov E., A. Gerasimov, A. Atanasov, V. Toshev, D. Petkov, D. Ivanov, L. Georgieva, L. Pavlova, H. Drenska, P. Vinarov, P. Petrov, S. Bachvarov, S. Panova, S. Bagarov, S. Serbezov, S. Stefanov, S. Dzhambazov, T. Stojkova, T. Datskova, H. Berlinov., *Technology of Ceramic Products and Materials*, Edited by Prof. Bachvarov S. (Saraswati press, Sofia 2003), pp 889-995.

2. Callister, William D., D. G. Rethwish., *Materials Science and Engineering: an introduction*, **8th** (Wiley 2009), pp588-600.

3. Mutafchieva, Gergana., L. Lakov., M. Aleksandrova., *Silicate Design of Hollow Ceramic Book to Illustrate Scientific and Secular Events*, NDT **IV** (2021), pp 286-287.

4. Tahir, Irfan., *Development of Silicone Mold Tool for Injection Molding Plastic Parts*, Degree of Master of Science in Mechanical Engineering University of Minnesota (2020), pp 6-8.

5. Mutafchieva, Gergana., *Modern Trends and Development of Lighting Fixtures in the Field of Silicate Design*, (National Academy of Arts Sofia, section Porcelain and Glass 2020, pp 100-116

6.https://www.zhermack.com/en/product_category/industrial/mould-making-industrial-en/master-mould/

Experimental analysis of creep behaviour of solder alloys at near eutectic point by using indentation test

Irida Markja [1,*], Klodian Dhoska[2], Dervish Elezi[3], Heinrisch Oettel[4]
[1,2,3] Faculty of Mechanical Engineering, Polytechnic University of Tirana, Albania
[4] Faculty of Materials Science and Technology, Technische Universität Bergakademie Freiberg, Germany

*imarkja@fim.edu.al ; irida.markja@gmail.com

Abstract: *Eutectic solder alloys are widely used in the microelectronics industry. The phenomenon of creep and its mechanisms are important aspects that influence the performance of solder alloys. During the last two decades, a Pb - solder alloys is fast becoming a reality in lead free electronic products due to harmful caused as toxic material to environment and health, international legislative pressure and marketing. The replacement of Sn - Pb alloys with Sn-Ag-Cu (SAC) alloys needs reliable results for assuring the usage of this solder joints material in electronic industry. In this paper has been studied the creep behaviour of a group of alloy in the system Sn-Ag-Cu (SAC) near the eutectic point. In this research work we have used three different alloy samples which are 95, 5Sn-3, 8Ag-0,7Cu, 96, 5Sn-3, 0Ag-0,5Cu and 95, 46Sn-3, 58Ag-0,96Cu. Indentation technique has been conducted to study the creep behaviour of these three SAC alloys by determining the creep parameters at different temperatures. The temperature used was at room temperature 30°C until 100°C and the stress used was 64MPa-178MPa for the indentation diameter 1 mm and 0.5 mm. The experimental method and results of the creep parameters like activation enthalpy Q, the stress exponent n of the power law model and the parameter of the material A were briefly described in this paper. From the creep curves, constructed for alloys and considered loads, the values of creep stress exponent n were determined for the studied alloys.*

Keywords: CREEP MECHANISMS, SN-AG-CU ALLOYS, CREEP STRESS EXPONENT *n*, INDENTATION TECHNIQUE.

1. Introduction

The purpose of this research work has been focused on the experimental study of the creep behaviour of a solder alloys at near eutectic point and in particular the determination of the reinforcement exponent *n* which is depending on the SAC microstructure.[1,2]

Indentation technique has been applied to study the creep behavior of this SAC alloys by determining the creep parameters at different temperatures. Based on it, the experimental study of the creep behavior through indentation instrument has become a useful technique to explore the dependence on time on the mechanical properties of materials and structures. Furthermore, the usage of the indentation technique is driven by the fact that this method requires minimal amount of study material as well as minimum sample preparation in comparison of the conventional method such as tensile test.

Three different samples such as 95,5 Sn-3,8Ag-0,7Cu, 96,5Sn-3,0Ag-0,5Cu and 95,46Sn-3,58Ag-0,96Cu have been used for determination of the creep behavior of SAC solder alloys at near eutectic point by using indentation test. The temperature used was at room temperature 30°C until 100°C and the stress used was at 64MPa until 178MPa for 1mm and 0.5 mm diameter. A constant load has been applied to the sample surface with a suitable penetrator for a period of time which largely exceeds the duration of the standard hardness test. The experimental method and results of the creep parameters like activation enthalpy Q, the stress exponent n of the power law model and the parameter of the material A were are estimated in this paper.

The goal of our experiments was to determine the creep behavior near room temperature depending on the microstructure of solder alloy Sn-Ag-Cu. The experimental method used was the indentation creep test. Indentation creep has become a useful technique for exploring the time-dependent mechanical properties of materials and structures and its recent advance is driven by the potential applications to small material structures, since the indentation creep experiment is inherently simple, accurate, and require minimum sample preparation (compared with the conventional methods such as the tensile test) [1,3,4].

2. Metallographic preparation of samples and experimental procedures

2.1 Metallographic preparation of samples

The materials were used in this study are Sn based solder alloys: 95,5Sn-3,8Ag-0,7Cu, 96,5Sn-3,0Ag-0,5Cu and 95,46Sn-3,58Ag-0,96Cu. The samples were produce in *Felder GmbH* company in Germany. The samples are prepared accordign to the standart ASTM 26 [5,6].

In figure 1 are presented the diagram for binary composition and the SAC ternary phase diagrame, that we have pointed the chemical positon for our samples and on the table 1 are presented the phase content of SAC ternary phase diagram[7,8].

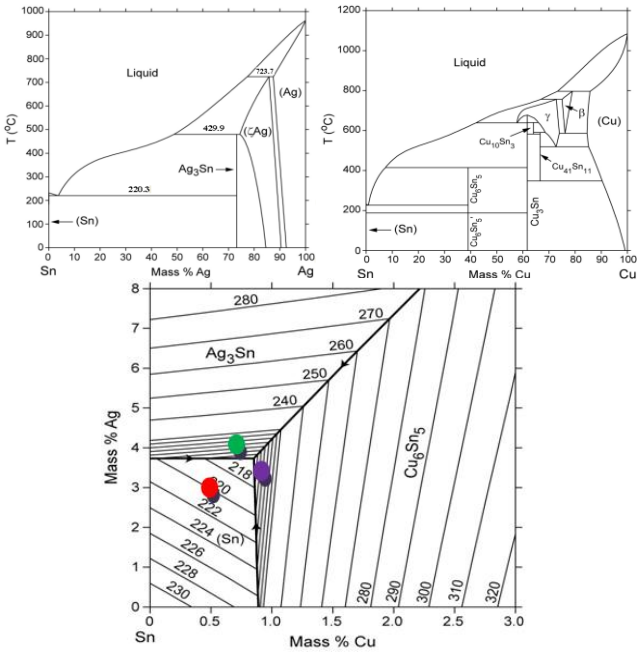


Fig.1 a)*Sn-Cu binary phase diagram ; b)Sn-Ag binary phase diagram ; c) Sn-Ag-Cu ternary phase diagram (Sn-rich corner); d) Sn-Ag-Cu ternary phase diagram [NIST]*

Table 1: *Phase contentof SAC ternary phase diagram*

Phase	*Density*	*Content of elements in phase%*			*Content of phases% mass*	*Content of phases% volume*
		Sn	*Ag*	*Cu*		
β-Sn	*7,31*	*100,00*	*0,00*	*0,00*	*92,65*	*94,14*
Ag3Sn	*9,93*	*26,83*	*73,17*	*0,00*	*4,89*	*3,66*
Cu6Sn5	*8,28*	*60,89*	*0,00*	*39,11*	*2,45*	*2,20*

2.2 Experimental procedures

The main objective in a creep test is to measure how a given metal or an alloy will perform under constant load, at constant temperatures. The indentation creep test (impression test) is schematically illustrated in Fig.2. A flat bottomed cylindrical punch of diameter is pushed into the creep test specimen under an applied pressure F load. The punch diameter used was 1mm, 0.75mm and 0.5 mm with a chemical composition of stainless steel and was used for creep test for temperature in the range 30^0C until 100^0C. The depth of indentation h of the punch is monitored as a function of time. The impression creep curve is derived by plotting the indentation versus time [9, 10,11,12].

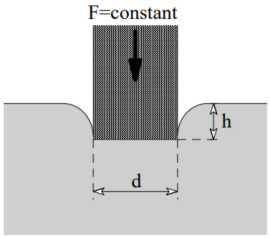
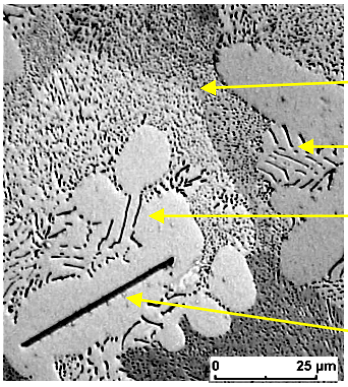


Fig.2 *Schematic of the indentation creep test [NIST].*

3. Experimental results

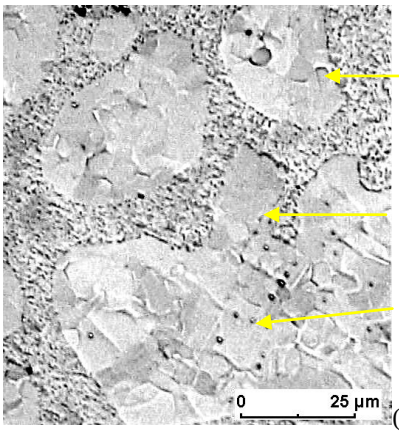
In SAC alloyes the formation of intermetallic compounds between the primary elements Sn, Ag and Cu in properties of alloys (Ag_3Sn,Cu_6Sn_5,Cu_3Sn). Precipitated particles of intermetallic compounds have a higher strength than the bulk of the material and also improve the fatigue resistance of solder alloys [13,14,15].

The metallographic examinations were carried out with the Neophot 30 light microscope (Carl Zeiss Jena) with a built-in digital color camera (JVC TK-C1381) carried out. The pictures were taken with the standard magnifications 25, 125, 250 and 500 times (figure 3). The microstructure of 95.5Sn-3.8Ag-0.7Cu contains the following ingredients: Base-Sn (1); Ag_3Sn lamellae which were even before thermal treatment near Sn dendrites (2); fine Ag3Sn particles which have been constituents of binary and tertiary eutectic and partially coagulated (3) and thicker Cu_6Sn_5 particles as constituents of ternary and coagulated eutectic (4).



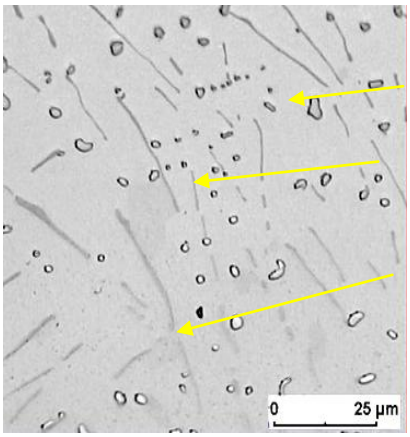
Ternary Eutectic
β-Sn, Ag_3Sn, Cu_6Sn_5;
Binary Eutectic
β-Sn, Ag_3Sn;
Dendrit
β-Sn;
Ag_3Sn

(a)



Ternary Eutectic
β-Sn, Ag_3Sn, Cu_6Sn_5;
Binary Eutectic
β-Sn, Ag_3Sn;
Dendrit
β-Sn;

(b)



Ternary Eutectic
Ag_3Sn, Cu_6Sn_5;
Binary Eutectic
Ag_3Sn;
Dendrit
β-Sn;

(c)

Fig.3*Microstructure of solder alloys performed with Light Microscope: a) 95.5Sn-3.8Ag-0.7Cu; b) 96.5Sn-3.0Ag-0.5Cu; c) 95.46Sn-3.58Ag-0.96Cu*

The temperature used was in the range 30^0C - 100^0C and the stress used was 64MPa-178MPa for 1mm, 0.75 mm and 0.5mm diameters. The following relations were used for all experiments (Table 2):

Table 2: *The relations used for our experiments: X-h-ε-έ*

X – chronometer value	
h – indentation	h=X/10
ε – deformation	ε = h/d
έ – creep rate	έ=Δh/Δt

The following graphs shows the results obtained from the experiments performed for the samples used in this study, depending on the *creep displacement dependence* **(**Table 3):

Table 3: *The creep displacement for three functions: έ-σ-T*

Creep displacement		***σ***	***Temp***
creep rate vs. deformation	*έ= function (σ)*	*102 MPa*	*TR,*
		77 MPa	*50°C ,*
		64 Ma	*80°C,*
		178 Mpa	*100°C*

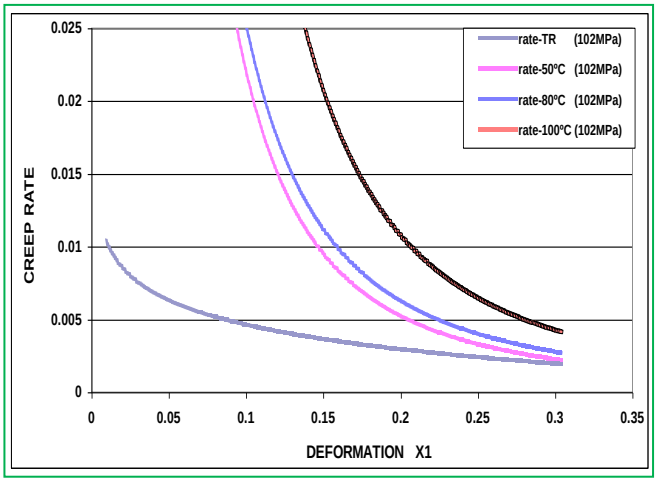


Fig.4 *The graphics show the functions for the dependence of creep rate vs. strain ε=funx(σ) for RT,50,80,100 °C , diameter 1mm and stress 120MPa*

The graph in figure 4 show the dependence of creep rate vs. strain ***ε=f (σ)*** for a load 800gr applied at the different temperature (**RT, 50, 80, 100**), the diameter **d=1mm,** and the stress **σ = 102MPa.**

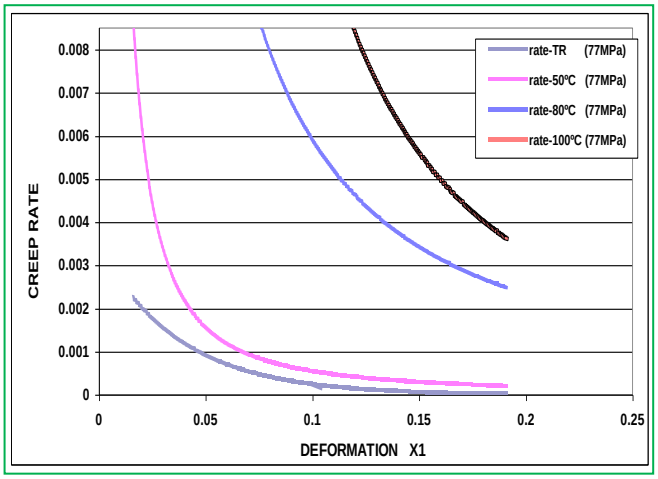


Fig.5 *The graphics show the functions forthe dependence of creep rate vs. strain ε=funx(σ)for RT,50,80,100 °C , diameter 1mm and stress 77 MPa*

The graph in figure 5 show the *dependence* of creep rate vs. strain ***ε=f (σ)*** for a load 800gr applied at the different temperature (**RT, 50, 80, 100**), the diameter **d=1mm,** and the stress **σ = 77 MPa.**

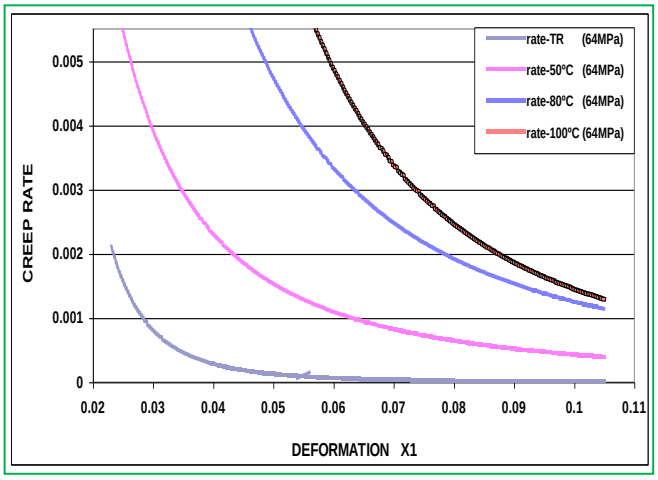


Fig.6 *The graphics show the functions for the dependence of creep rate vs. strain ε=funx(σ)for RT,50,80,100 °C , diameter 1mm and stress 64 MPa*

The graph in figure 6 show the dependence of creep rate vs. strain ***ε=f (σ)*** for a load 800gr applied at the different temperature (**RT, 50, 80, 100**), the diameter **d=1mm,** and the stress **σ = 64 MPa.**

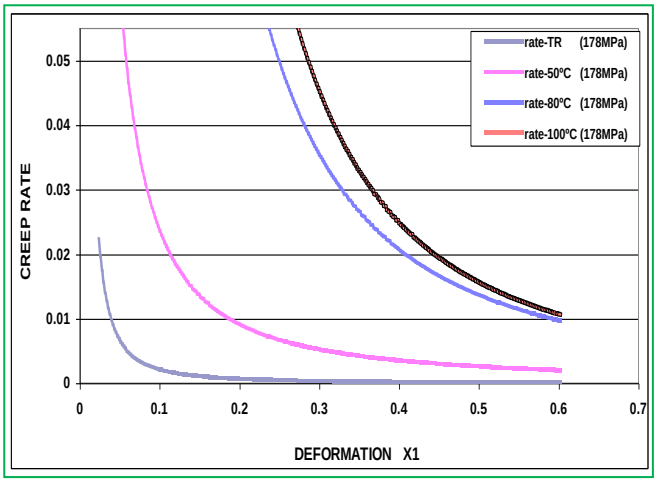


Fig.7 *The graph show the dependence of creep rate vs. strain ε=funx(σ)for RT,50,80,100 °C , diameter 0.5mm and stress 178 MPa*

The graph in figure 7 show the dependence of creep rate vs. strain ***ε=f (σ)*** for a load 800gr applied at the different temperature (**RT, 50, 80, 100**), the diameter **d=0.5mm,** and the stress **σ = 178 MPa.**

4. Discussions and Conclusions

From our experimental study we can draw the following interpretations and conclusions:

1. The realization of the experiments tests of the creep evaluation of the SAC alloys in the laboratory equipment with indentation test. The equipment was initially adjusted for the upper stress limit (with Fe sample) and for the lower stress limit (with Sn sample).

2. For the case of pure Sn sample, the exponent of stress was also evaluated, according to the law of power, which resulted: $n = 2.4$. This value is between the interval which are evaluated from other authors in different study referred to creep behavior SAC (1.8 - 2.8).

3. For the alloy 96,5Sn-3,0Ag-0,5Cu-IIRL we found $n = 6.3$ which can be said to show a higher creep resistance compared to the samples with long-term aging, probably due to intermetallic particles in large quantities that can be in the microstructure.

4. For the alloy 95, 5 Sn-3, 8Ag-0,7Cu we find the exponent $n = 5.6$ for the aging time at 200 ° C of 170 hours, and $n = 7.5$ for the aging times 340 and 510 hours.

5. Even in our study it has been found that with the increase of the applied strain the minimum velocity of creep deformation increases, in the second stage.

6. For a more complete interpretation of the creep behavior of SAC bonds it is necessary that the study proceed with the evaluation of the size of the intermetallic particles as well as the nature of the matrix particleboards.

7. Future work will be focused on the investigation of microstructures of our samples for evaluation of precipitates into the matrix.

10. Acknowledgment

The authors gratefully acknowledge the TU Bergakademie Freiberg, Germany for providing the SAC alloy samples used in this work, part of the project 'Network of Materials Science and Engineering (NMST)'supported by DAAD and Polytechnic University of Tirana for partial funding of this study.

9. Conflict of interests

The author would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

10. References

1. I.Markja, K. Dhoska, D. Elezi, Experimental Study of Creep-behavior by using Indentation Test To Solder Alloys Sn-Ag-Cu near Eutectic'2nd "International Conference "Engineering and Entrepreneurship" Proceedings, Albania Tirana, 10-11 October (2019);
2. K. Dhoska.; J. Kacani.; H. Oettel.; V. Ramaj. Creep Behavior of a Sn-Ag-Cu Alloy Near Room Temperature. In proceedings of the 11th International Research/Expert Conference"Trends in the Development of Machinery and Associated Technology", Hammamet, Tunisia, 05-09 September, pp. 307-310. (2007)
3. A.S.T.M.24, "Metallographic and Materialographic Specimen Preparation" ISBN 978-0-8031-4265-7 (2007)
4. Y. M.Leong.; A.S.M.A. Haseeb. Soldering Characteristics and Mechanical Properties of Sn-1.0Ag-0.5Cu Solder with Minor Aluminum Addition. Materials 2016, 9(7), 522. pp. 1-17.
5. J.Gomez, C. Basaran 'Nanoindentation of Pb/Sn solder alloys; experimental and finite element simulation results' International Journal of Solids and Structures 43 (2006) 1505–1527
6. I. Markja "Diploma Thesis: Experimental study of creep with the indentation test to solder alloys" TUF Germany and PUT Albania (2009)
7. M.E. Kassner, M.T.P.Prado; Fundamentals of creep in metals and alloys; ISBN 0-08-04367-4 Elsevier (2004)
8. https://www.metallurgy.nist.gov/phase/solder/agcusn.html (NIST)
9. https://d-nb.info/1011669226/34
10. K.S. Kim, S.H. Huh, K. Suganuma, "Effects of cooling speed on microstructure and tensile properties of Sn-Ag-Cu Alloys", Materials Science and Engineering, A333, (2002), S. 106-114.
11. C.S. Ohy, J.H. Shim, B.-J. Lee , D.N. Lee, "A Thermodynamic Study on the Ag-Sb-Sn System", Journal Alloys and Compounds 238, (1996), S. 155-166.
12. C.M. Miller, I.E. Anderson, J.F. Smith, „A Viable Tin-Lead Solder Substitute: Sn-Ag-Cu", Journal of Electronic Materials, Vol. 23, No. 7, S. 595- 601; (1994).
13. M.E. Loomans , M.E. Fine, "Tin-Silver-Copper Eutectic Temperature and Composition", Metallurgical and Materials Transactions A, Vol. 31A, S. 1155-1162; (2000),
14. J.Y. Park, C.U. Kim, T. Carper, V. Puligandla, "Phase Equilibria Studies of Sn-Ag-Cu Eutectic Solder Using Differential Cooling of Sn-3.8Ag-0.7Cu Alloys", Journal of Electronic Materials, Vol. 32, No. 11, pp. 1297-1302; (2003)
15. I. Ohnuma, M. Miyashita, K. Anzai, X.J. Liu, H. Ohtani, R Kainuma, K. Ishida, "Phase Equilibria and the Related Properties of Sn-Ag-Cu Based Pb-free Solder Alloys", Journal of Electronic Materials, Vol. 29, No. 10, pp. 1137- 1144, (2000)

Real time capturing welding parameters with tracking module

Deyan Gradinarov[1], Yuri Bijev[1]
Institute of Metal Science, Equipment and Technology with Hydroaerodynamic Center at Bulgarian Academy of Sciences[1]
dgradinarov@ims.bas.bg

Abstract: *It is presented real time capturing voltage and current in welding process with module Lincoln Arc Tracker.*
Keywords*: WELDING PROCESS, CURRENT CAPTURING, VOLTAGE CAPTURING, REAL time*

1. Introduction

According to the modern requirements for low energy intensity and environmental protection and in the context of declining natural resources, scientists, the business, and the society are looking for ways to meet the growing needs of various industries, from optimizing and improving welding methods to adding additional alloying elements for better weldability.

The welding process is used in almost every area of human activity, and the need products of this process is constantly increasing. With the increase of the responsibility of the welded joints, the requirement for welding quality is also increased.

The welding process is performed according to a pre-approved and validated Welding Procedure. This welding procedure sets the welding technology, welding mode, current, voltage, welding speed, wire feed rate, flux used, type, diameter and tip pre-forming of the welding wire, welding and break time, and other parameters on which the quality and reliability of the welded joint depends. Deviating from them, with a high probability, leads to a decrease in the properties of the welded joint, and hence to defects and damage that increases the risk of injuries and endangering human life and negative environmental consequences.

When welding by an operator, due to a number of factors that cannot be avoided, the welder can deviate from the welding procedure, with the welding process being carried out at welding parameters that differ from the procedure. This leads to the presence of defects - gas and slag inclusions, welding cracks, unexpected change of the main metal properties in the surrounding area, etc. The presence of such defects directly affects the exploitation properties of the manufactured parts and elements by reducing their strength, lifetime, reliability, etc. When applied conscientious control, this leads to wastage, cost increases and waste of resources - metal, welding wire, welding gases and energy. In case of unconscious control - to the direct danger of traumatism, accidents, ecological catastrophes, etc., which directly or indirectly affects the society.

Improving the welding process by the real time control of welding parameters compared to those set in the welding procedure reduces drastically the possibility of defects and thus gives economic and environmental advantages by reducing wastage and consequently consumption of metal, gas, electricity and water to reducing emissions.

The results of the research show that there are numerous studies on the methods and technologies for monitoring and control of the welding parameters, the influence of the parameters on the exploitation properties of the welded elements, the quality determination of the welded joints.

It is studied the influence of the welding parameters in various welding processes and their impact on the quality and performance of the welded joints [1,2,3].

One of the current problems of modern material science is methods for increasing the life cycle of parts with welded joints, which must have both high hardness and strength and low internal stress. It is studied the impact of welding parameters on the morbidity of welded joints [4,5].

There are known studies on welding process optimization methods by control of welding parameters [6,7,8].

There are studies on welding parameters control and welding optimization [9,10] as well as methodologies for determining the parameters in welding processes [11].

There are developed welding parameters parameter control systems [12,13,14].

The analysis of our well-known sources does not give enough clarity to the question: what impact the welding parameters have on the performance of the welded joints and what methodologies should be used to improve the quality of the process.

This leads to the need to acquire new fundamental knowledge about the possibilities, means and rate of improving the quality of the welding processes by real time control of parameters.

A thorough study and determination of the influence of welding parameters on the quality of the process and analysis of the possibilities for quality improvement through real time control is also needed.

2. Capturing welding parameters – voltage and current

As a capturing module is chosen Lincoln Arc Tracker. With this module we can capture in real time welding current up to 1000A and voltage up to 44V. This module has an ethernet connector to easily connect it in to a local network. The module is combined with software product Power wave manager which captures tracked welding parameters. With this capturing process can be monitored in real time on remote computer.[15]

The set up consists of welding torch, which is mounted on mechanical grip. The mechanical grip fixes the torch in one position and removes fluctuations from welder's movements. The mechanical grip is mounted on welding tractor, which moves along and over the welded elements with constant speed. Welded elements are placed on welding table. Next to the welding table are placed the power source that feeds the torch and gas bottle that protects the joint. Capturing module Lincoln Arc Tracker. Arc tracker captures welding current and voltage. It is connected to WiFi Router that transmits the data to laptop. Connection of the Arc tracker module is shown on Fig. 1.

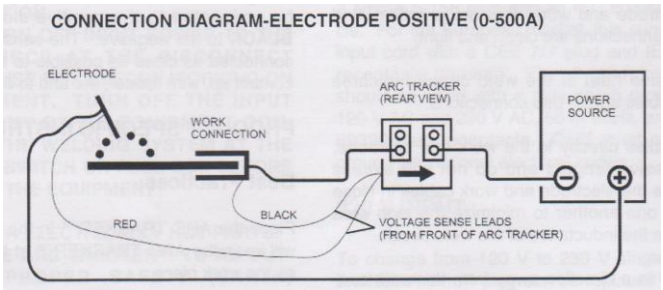


Fig. 1 *Connection diagram of Arc Tracker in the experimental set up.[15]*

The set up functionality is verified with experiment with the following parameters:

- welding current – 210A
- welding volatage – 25V;

- η of the welding source – 0,8;
- welding power – 4200J/s;
- welding speed – 50cm/min;
- welding steel plates 50x5x200mm.

On Fig.2 are shown values of set and measure welding current.

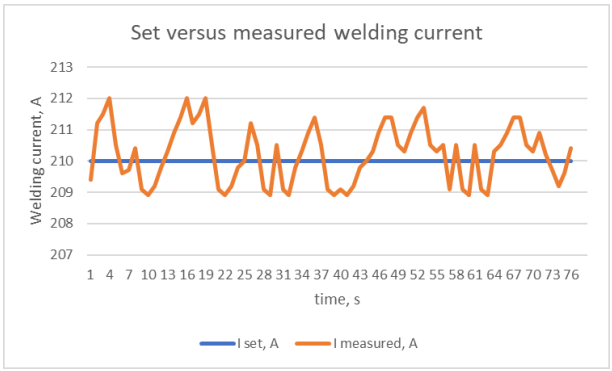


Fig. 2 *Set versus measured welding current curves.*

On Fig.3 are shown values of set and measure welding voltage.

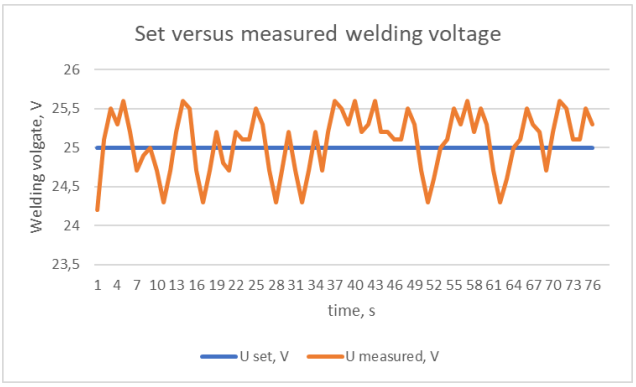


Fig. 3 *Set versus measured welding voltage curves.*

On Fig.4 are shown values of set and measure welding power.

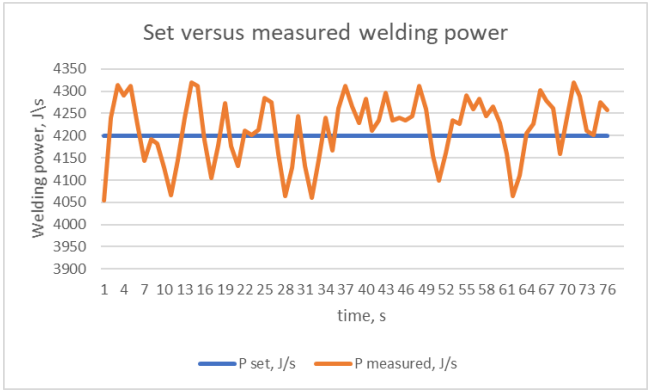


Fig. 4 *Set versus measured welding current power.*

On Fig.5 are shown set versus measured welding current, voltage and power differences.

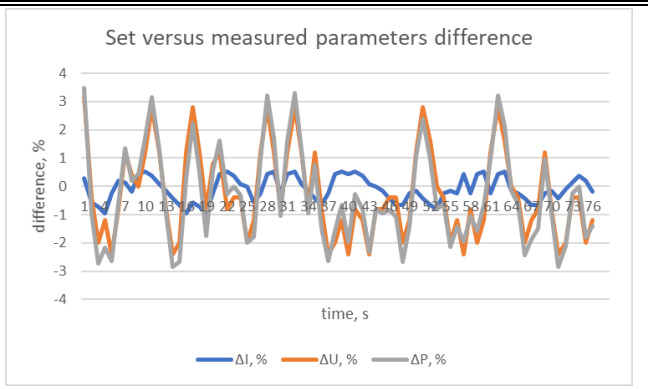


Fig. 5 *Set versus measured welding parameters.*

Measured welding current and voltage don't deviate much from set values. This gives the expectation that the welded joint would be of good quality.

3. Conclusions

It is presented tracking module for real time capturing welding current and voltage during a welding process. Parameters are shown graphically on remote laptop and a warning signal value limitation can be triggered if measured values goes off.

Acknowledgments

This work was made possible by a project KP-06-N37/31, funded by the NSF.

All equipment and experimental units used in this work was funded by the European Regional Development Fund within the OP "Science and Education for Smart Growth 2014 - 2020", project CoE "National center of mechatronics and clean technologies", № BG05M2OP001-1.001-0008-C08

4. *References*

1. H. Dong ; M. Cong ; Yu. Zhang; Yu. Liu ; H. Chen, Real time welding parameter prediction for desired character performance, IEEE International Conference on Robotics and Automation (ICRA), 2017
2. E. Karadeniz, U. Ozsarac, C. Yildiz. The Effect of Process Parameters on Penetration in Gas Metal Arc Welding Process. Materials and Design. 28(2):2007; 649–656.
3. P. Tashev, „Modeling of temperature processes in automated TIG welding overlay and samples with plain surface“, Collection of reports, Vth National conference with foreign participation „„Metal science, hydro- and aerodynamics and national security '2015“, 22 – 23 October 2015, Sofia, ISSN 1313-8308
4. P. Ghosh, S. Gupta, P. Gupta, R. Rathi, Fatigue Characteristics of Pulsed MIG Welded Al-Zn-Mg Alloy. Journal of Material Science. 26(22):1991; 6161–6170.
5. N. Takuo, M. Takashi, K. Katsuhiro, Deformation and Fatigue Characteristics of Large Welded Bellows with Inclined External Edge, Materials Transactions, Vol. 49, No. 6 (2008) pp. 1249 to 1255, 2008 The Japan Society for Technology of Plasticity
6. I. Kim, M. Park, A Review on Optimizations of Welding Parameters in GMA Welding Process, Journal of Welding and Joining, Vol. 36, No. 1, 2018, pp. 65-75, ISSN 2466-2232
7. V. Chauhan, G. Khandoori, A. Kumar, Role of Taguchi Design of Experiment in Optimization of Welding Process Parameters for Different Materials-A Review. International Journal of Advanced Technology & Engineering Research (IJATER). 2014; 146–151
8. D. Kim, M. Kang, S. Rhee, Determination of Optimal Welding Conditions with a Controlled Random Search Procedure. Welding Journal. 2005

9. G. Posch, J. Bruckner, H. Ennsbrunner, INDUSTRY 4.0 IN WELDING, Fronius International, 2017
10. P. Hammersberg, H. Olsson, Proactive Control of Weld Dimensions in Robot MAG Welding. 2013
11. P. Tashev, A. Tasev, M. Manilova, Ya. Lukarski, Methodology for defining technological parameters of resistance welding of cross wires, VIth International Metallurgical Congress, Ohrid 2014
12. https://play.google.com/store/apps/details?id=com.kemppi.arcmobilecontrol&hl=en_US
13. https://www.boschrexroth.com/en/xc/products/product-groups/welding-technology/controllers-with-power-section/mf-system-prc7000/prc7300/prc7300-2
14. http://www.linde-gas.com/en/products_and_supply/welding_safety_products/digital-welding-management/index.html
15. Operator's manual of Lincoln Arc tracker, Lincoln Global Inc. 16.05.2018

World technology market: features and current trends

Galyna Zhavoronkova, Vladimir Zhavoronkov, Natalia Kovalenko, Irina Panasiuk,
National Aviation University,
Kyiv, Ukraine
zhavor@ukr.net

Annotation. *The definition of the world technology market is given and its features are characterized. The structure of the world technology market formed by institutional elements is considered. The following segments of the world technology market have been studied: the market of patents and licenses, the market of scientific and technological products, the market of scientific and technological specialists, the market of high-tech capital. According to Ukraine's ratings in the world technology market (2018-2019), the reasons for its lag in it are named. The tendencies of the world market of technologies are substantiated.*
KEYWORDS: HIGH TECHNOLOGIES, PATENTS, LICENSES, SCIENTIFIC AND TECHNOLOGICAL PRODUCTS, SCIENTIFIC AND TECHNOLOGICAL SPECIALISTS, HIGH-TECH CAPITAL.

1. Introduction

In the modern post-industrial economy there is a new paradigm of the world order, in which competition is based on knowledge. The country's ability to create and implement its own innovations and develop high technologies is becoming a key resource for sustainable economic development, financial stability, and competitiveness. This ability determines the place in the world economic space [1].

The world economy demonstrates the focus of national economic systems on the intensive development of high-tech products. A qualitative change in the system of world economic relations was the formation of the world technology market, which today is global in nature.

The formation of the world technology market took place in the second half of the twentieth century, when the volume of international commercial transactions in technology exceeded the scale of national exchange. This made it possible to distinguish international technology exchange into a separate form of international economic relations.

According to the IMF, the number of countries exchanging technologies only during the 60's to 90's of the twentieth century. Increased from 22 to 84 [2]. The volume of annual licensing transactions has significantly expanded. Per unit cost, the currency effect of the sale of technological resources on the world market is much higher than the export of ordinary goods. Technological exchange exceeds traditional international flows of goods, services and capital.

The global technology market is a set of international market relations of entities regarding the commercial use of property rights to its objects (productive technologies, process technologies and management).

The scientific and technical potential of countries, the state of their participation in the international division of labor and international technological exchange gives many advantages, determines the modern picture of the world and its development. This process most fully reflects the model of the world economy "Center - Periphery", according to which the world economy consists of two interconnected and interdependent parts - the center and the periphery, the relationship between which is mainly "dominance - dependence".

Center - countries that are mainly members of the Organization for Economic Cooperation and Development. The periphery is structured and splits into separate "concentric circles" equidistant from the center. Distance is determined by the level of economic and social development on the principle: the farther from the center, the worse. The locations of these countries are defined as follows: East Asia, Eastern Europe, Russia, India, Latin America, African countries and the Arab-Muslim world.

The objective prerequisites for global development and acceleration of technology in modern conditions are:

- formation of information and technological structure of social development;
- increasing priority, compared to the triad of factors of production (capital, labor, natural resources), and today the fourth factor - innovative entrepreneurship, which is simply defined as technological;
- increasing the requirements of the world community to minimize technological and anthropological impact on the environment.

2. Features and structure of the world technology market

The structure of the world technology market is formed by institutional elements that mediate the movement and interaction of world technologies. The institutional elements of the global technology market include:

- objects - products or processes - carriers of technology;
- subjects - legal or natural persons;
- commercial and non-commercial technology transfers. The main forms of commercial technology transfer are: sale of patents; sale of licenses; sale of know-how, leasing; copyright agreements; franchising; provision of knowledge-intensive services. Non-commercial forms of technology transfer include international technological assistance - technological grants (free provision of technology and equipment, consulting and training, etc.); co-financing of projects (part of the costs is covered by the company or the recipient country); use of technologies to obtain a social or environmental effect;
- forms of transfer and legal protection of innovations and technologies (patents, licenses, know-how, leasing, franchising, copyright);
- channels of transfer and diffusion of innovations and technologies (trade in innovative products, licensed trade, scientific-technical and information cooperation, etc.).

The global technology market is heterogeneous in its structure and includes four segments:

1. The market of patents and licenses. The most dynamic segment of the technology market is the market of licenses and patents with an annual growth of over 10%. The leading exporters and importers of the license and patent market are industrialized countries that register patent applications (Table 1).

2. The market of science and technology-intensive products (Table 2). The international exchange of scientific and technical knowledge has an objective character of development. The exchange is an objective necessity, allowing to widely introduce into production the latest achievements of world scientific and technical thought. This leads to the growth of the exchange of scientific and technical knowledge in various forms of interaction and joint efforts of large companies to solve current problems of science.

An important component of the global technology market is the export of high-tech products.

Table 1 *Patent applications (2018-2019)*

Country	2018		2019	
	Value	Place in the ranking	Value	Place in the ranking
Japan	496,46	1	490,35	1
Republic Korea	444,63	3	461,15	2
Taiwan, China	480,33	2	447,42	3
Switzerland	322,48	4	321,65	4
Sweden	271,58	7	256,32	6
Finland	285,97	6	255,31	7
USA	144,09	13	143,99	13
Singapore	121,25	14	118,66	15
Norway	115,24	16	113,69	17

Source: grouped by authors according to data [6].

Table 2 *Scientific publications (2018-2019)*

Country	2018		2019	
	Value	Place in the ranking	Value	Place in the ranking
USA	2002,3	1	2088	1
Great Britain	1235,7	2	1289	2
Germany	1083	3	1131	3
Japan	887,3	6	919,3	6
Switzerland	834	9	867,7	9
Sweden	749,3	98	779,3	11
Finland	545,7	19	571	19
Norway	502,7	20	532,3	20
Singapore	466,7	24	493,7	23

Source: grouped by authors according to data [6].

Leading positions in the export of high-tech products (Table 3) has Germany (10.8% of total world exports of high-tech goods), followed by South Korea, China, the United States and Singapore (they account for 45.05%). The total volume of exports of high-tech goods in 2018 was estimated at about 2 trillion. dollars USA. Exports of high-tech products from developing countries are growing twice as fast as the corresponding exports from developed countries. This indicates the strengthening of the global high-tech market in Asian countries.

Table 3 *World leaders in the volume of exports of high-tech products as at 01.01.2019*

Country	Export volume, million USD
Germany	209,610
South Korea	192,789
SAP Hong Kong, China	161,877
USA	156,365
Singapore	155,446
France	117,814
Japan	111,020
Malaysia	90,395
Netherlands	85,790
Great Britain	76,533

Source: grouped by authors according to data [6].

3. The market of scientific and technological specialists. The creation of a high-tech sector is facilitated by the presence of highly qualified specialists and a large number of high-tech startups. An important characteristic of the labor market is its diversity (Table 4), which means similarities and differences between workers in terms of age, cultural background, physical abilities and disabilities, race, religion, gender and sexual orientation.

Table 4 *Diversity of the workforce (2018-2019)*

Country	2018		2019	
	Value	Place in the ranking	Value	Place in the ranking
Singapore	5,8	2	5,8	1
UAE	5,7	5	5,7	2
Australia	5,6	8	5,7	3
Canada	5,9	1	76,4	5
USA	5,8	3	5,5	7
Qatar	5,4	12	5,5	10
Romania	5	26	5,3	18
Sweden	5,4	13	5,2	20
Switzerland	5,5	11	5,2	21

Source: grouped by authors according to data [6].

4. High-tech capital market.

Industrialized countries account for about 90% of the world technology market, including more than 60% are in the United States, Japan, Britain, Germany and France.

Most of the trade in licenses in the global technology market, of the total volume of commercial transactions, falls on the following industries:

- electrical and electronic industry – 19%;
- general mechanical engineering – 18%;
- chemical industry – 17.4%;
- transport engineering – 10.2%.

The objects of the world technology market are goods classified according to the technological capacity of trade developed by UNCTAD, which is indicated as the ratio of research and development costs to the total cost of production and trade in goods. However, the largest percentage of the state budget for research is spent by Israel and the Republic of Korea (Table 5).

Table 5 R&D expenditures (2018-2019)

Country	2018		2019	
	Value	Place in the ranking	Value	Place in the ranking
Israel	4,3	1	4,3	1
Republic Korea	4,2	2	4,2	2
Switzerland	3	8	3,4	3
Sweden	3,3	4	3,3	4
Japan	3,3	3	3,1	6
Finland	2,9	9	2,7	10
USA	2,8	11	2,7	11
Singapore	2,2	17	2,2	14

Source: grouped by authors according to data [6].

Objects presented in an intangible form are the result of intellectual activity and are intangible carriers of various types of technology. Such objects can be classified by internal integrity into:

- non-market (information arrays, knowledge, experience and skills acquired during research and can be transferred through training, internships, exchanges and migration of specialists);
- potential market (patents, know-how, scientific and technical documentation, management consulting);

- market (patent and non-patent licenses, engineering, leasing, franchising, research services, staff training).

In the world market of technologies there are subjects of all structural levels:

- micro level - universities, research institutions, business centers, venture firms, individual innovators;

- meso level - TNCs, national companies, science and technology complexes (technology and research parks, which are the leading implementers and patenters of innovations);

- macro level - state and national scientific and technical systems that ensure the functioning and development of the global technology market;

- mega-level - interstate formations and integration groups, within which efforts are focused on certain areas of STP;

- metalevel - international organizations, including the United Nations, which provide technical assistance to countries that develop and shape the world market for economically safe technologies.

The most important role in all segments of the global technology market is played by the following countries: USA, Japan, Great Britain, Germany, France.

They account for 60% of international technological exchange. In general, industrialized countries account for about 90% of the global technology market, and developing countries - 10%.

For the former socialist countries and republics of the Soviet Union, the share of high-tech exports is much smaller. This is a consequence of the landslide deindustrialization of the former USSR and Eastern European countries in the 1990s. Only the Czech Republic and Poland stand out in a positive way. Thus, Ukraine in this area belongs to the periphery of the technology market and has the following ratings (Table 6).

Table 6 Ratings of Ukraine in the world technology market (2018-2019)

Country	2018		2019	
	Value	Place in the ranking	Value	Place in the ranking
Diversity of the workforce	4,5	62	4,6	59
Scientific publications	215,7	50	229,3	50
Patent applications	1,41	62	1,56	62
R&D costs	0,6	56	0,4	67
Trademark applications	653,88	60	744,49	59
Quality of research institutions	0,04	44	0,04	44
Cooperation with many stakeholders	3,7	56	3,8	58
International joint inventions	0,5	56	0,53	55
The state of cluster development	3,2	106	3,5	96

Source: grouped by authors according to data [6].

Modern processes of globalization have affected the structure of the global technology market and identified a number of its features, namely:

• the world market of technologies contributes to the intellectualization of the world economy in general [3];

• the main actors are TNCs, which share the results of research and development by parent and subsidiary companies, as a result of which the global technology market is better developed than the national [4]. 2/3 of the world's technological exchange is accounted for by intra-firm exchange of TNCs. More than 60% of licensed revenues of industrialized countries account for the share of intra-corporate revenues (in the US - 80%) [5];

• the largest TNCs concentrate research on themselves and contribute to the monopolization of the world technology market (the level of monopolistic control is 89–90%) [3];

• technological gap between different groups of countries causes a multi-stage structure of the global technology market;

• the global technology market has a specific regulatory framework (International Code of Conduct on Technology Transfer), as well as international regulators (World Trade Organization Agreement on Intellectual Property Rights) (TRIPS), the UN Conference on Technology Transfer Committee and Development (UNCTAD), the World Intellectual Property Organization (WIPO), the Export Control Coordinating Committee (COCOM), the Technology Security Expert Meeting (STEM)).

3. Trends in the global technology market

The trends of the world market of high technologies include:

- a high degree of monopolization of the world technology market. This is due to the fact that the implementation of research and development requires significant costs, which can only be done by the largest companies or countries;

- stable dominance in the world market of technologies of industrialized countries, whose share in the international scientific and technological exchange is almost 90%. Exports of high-tech products account for the five most developed countries in the world: the United States, Japan, Britain, Germany and France. In Europe, technology exchange takes place mainly within the EU, most often inter-firm exchange;

- formation of a two-tier structure of the market of high-tech goods and services by relocating production to countries with lower labor costs and widespread use of outsourcing. This applies to the countries of Southeast Asia. Leaders in outsourcing are India and China);

- high level of monopolization of the world market of high-tech products (over 90%) (due to the unique properties of high-tech goods and the transformation of multinational corporations into major market players). Concentration of scientific and technical developments in transnational corporations, joint use of R&D results by parent and subsidiary companies contribute to the development of the global technology market, allows the establishment of monopolistically high prices for patented products and control over the market as a whole;

- an increase in the number of small and medium-sized venture firms (corporations transfer to them the risk of research and development, development of new products, testing of innovations).

The United States remains one of the top five countries in terms of both high-tech exports and imports, despite growing competition. Take the lead in the market of telecommunications, computer and information technology, software (the most famous are Apple, Cisco, Hewlett-Packard, IBM, Intel, and Microsoft). The country dominates the export of computer equipment (75%) and software (65%), remains the world leader in innovation (although most research and innovation focuses on products that are produced abroad and then exported back to the United States). The main trends in the high-tech sector are the development of social media platforms and the active introduction of "cloud" technologies.

The threat to the United States is caused by the penetration of Chinese companies into the American market. To reduce the competitiveness of Chinese companies, a ban on the sale of programs used in sensors, drones and satellites to automate the recognition process. In 2020, the US government imposed restrictions on the export of artificial intelligence technologies. But the US high-tech market has a margin of safety, many of the leading high-tech corporations and firms are American; there is no absorption of American companies by European ones, on the contrary, there are reverse processes; higher education is more in line with the needs of the innovative economy, and higher education is more qualified and prestigious; high-tech products meet the high demands of consumers. Concealed protectionism is an instrument of state support for the high-tech sector of the American market.

The European high-tech market is inferior to the following countries: the United States in areas such as telecommunications and electronics; Japan and the newly industrialized countries of Southeast Asia - in the field of mass production of knowledge-intensive goods. The number of European high-tech companies in the domestic market is only 30-40% of their total. With high energy prices and declining sales, big business has reduced its IT spending, and small and medium-sized enterprises cannot afford to invest heavily in this area.

The reasons for the weakness of the European high-tech market are:

- reduction of demand for ICT compared to the rest of the world;
- insufficient funding for research by states;
- lack of qualified personnel and reduction of graduates in engineering, mathematics and information specialties;
- there is an innovation deficit.

According to a study by Euromonitor International, the production of high-tech goods in the EU is expected to triple and reach 16 trillion US dollars in 2030 through the pooling of resources for investment in several high-tech industries, including the development of innovation in the Internet of Things and the creation "Smart" companies. Finland, Denmark, Sweden and Norway are considered to be the most ready for this.

A common feature of the Asian segment is the crucial role of the state in the effective development of advanced technologies. Japan is one of the leaders in the world market for high-tech goods and is one of the largest competitors in the United States. The main driving forces in the development of high-tech industries in the country were political factors, especially active interaction with the United States and external demand and external financial resources. Japan ranks first in the export of electronics and information.

4. Conclusions

1. The world technology market is one of the most important factors in the development of the world economy as a whole.

2. The growth rate of international technology exchange significantly exceeds the growth of traditional world economic flows, including money capital.

3. The growth of the world market of technologies reflects the objective need for the formation of new systems of productive forces, the introduction of new technological components.

4. Technology is becoming the main determinant that affects all areas of individual and social life and the process of transformation of the technological structure of planetary civilization.

5. Leadership in the development of high technology was achieved by those countries that were aimed at producing competitive products based on their own innovative developments and focused primarily on the European market.

6. The main limitations of intensifying the participation of Ukrainian entities in the processes of technology transfer in the foreign market are:

1) the level of a significant number of domestic scientific developments and science-intensive product does not meet the requirements of the modern market;

2) violation of the system of interaction (cooperation) of research institutions and enterprises in the development and commercialization of science-intensive products;

3) shortage of resources (financial, personnel) for the implementation of innovative activities of enterprises on their own, as well as for the acquisition of innovations abroad;

4) lack of mechanisms for implementing the programs and concepts of scientific and technical development declared by the state.

5. References

1. Zhavoronkova G., Zhavoronkov V. The technological imperative and technological safety in the systems of national security of the state // Security and future. 2/2018. P.63-66.

2. International Monetary Fund [Electronic resource]. – URL: http://www.imf.org/external/ns/cs.aspx?id=28.

3. Lukin S. Y. Ukraine in the modern market of science-intensive products / S. Y. Lukin, R. P. Kozachenko // Economic space. – 2008. – 11. – P. 29–35.

4. Zhavoronkova G., S. Miziuk, V. Zhavoronkov. The influence of transnational corporations on the economy of developing countries (Contemplating the example of how the Coca-Cola Company influences the economy of Ukraine) // Science. Business. Society. – Vol. 5 (2020). – P. 9-13.

5. Technological Developments and their Effects on World Trade [Electronic resource]. – URL: http://ideas.repec.org/p/wpa/wuwpit/0108006.html.

6. The Global Competitiveness Report 2018 and 2019. World Economic Forum. Official website. [Electronic resource]. – URL: https://www.weforum.org/reports/

Tax challenges of home office regime following the COVID-19 pandemic

Jana Kubicová
University of Economics in Bratislava, Slovakia
jana.kubicova@euba.sk

Abstract: *Covid-19 pandemic has made it necessary to move work from employers' workplaces to home offices. The employee works from home using digital technologies. However, the Home Office scheme is accompanied by significant employee costs, covered by private employees' funds. Among them for example cost of electricity, water, sewers, the cost of suitable workplace equipment and its amortization, costs of quite free space, cost to cover speedy internet. On the other hand, the employers receive work from the employees, but the cost of the working environment and resources they save significantly. The Home Office regime will remain in place after the pandemic, so it is time to consider a financial solution to the cost of home office staff – for example, in the form of tax instruments.*

Keywords*: DIGITALIZATION, MEASUREMENT, EFFECTS OF REMOTE WORK, EMPLOYEES EXPENDITURES, TAX DEDUCTIBLE ITEM*

1. Introduction and review of literature

From March 2020, every aspect of our lives is exposed to a new situation – the COVID-19 pandemic. Technologies, including information technology and digitalisation, are importantly helping to combat the pandemic. According to Fournier, "the digital economy is an area of economics that is engaged in studying the cost of intangible goods traded over the internet." (Fournier, 2013) One of the first definitions of digitalisation was authored in 2001 by Mesenbourgh and Atrostic who state the digital economy has three prims - supporting infrastructure, electronic business processes (how business is conducted), and electronic commerce transactions (selling goods and services online). They add that reliance on computer networks, and the benefits they can provide, is the "bottom line" difference between electronic and other kinds of business. (Mesenbourg & Atrostic, 2001) According Muggah, Rohozinski and Goldin „COVID-19 is accelerating the shift towards digitalisation, ... and the digital economy is growing faster than the real economy. Depending on how it is defined, its total value could be 11.5 trillion USD, or 15% of global GDP. Researchers believe this could rise to as high as 37 trillion USD, or 26% of GDP, by 2040. "(Muggah R. R., 2020)

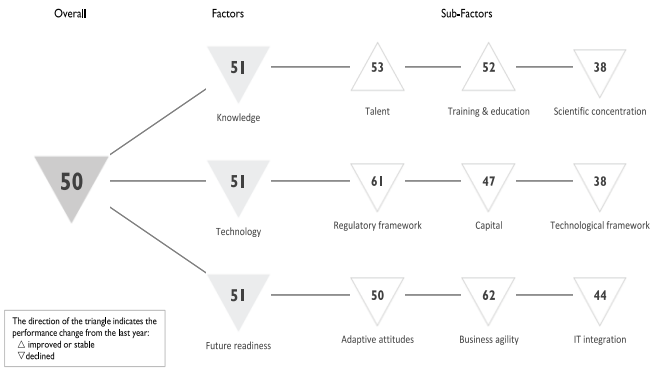


Figure 1 *IMD World Digital Competitiveness Ranking (WDCR) – Slovak republic, overall performance (2020)*
Source: (IMD World Competitiveness Center, 2020, p. 144)

A number of indicators are used to measure and compare countries' readiness in the field of digitalisation internationally. Among them, for example *IMD World Digital Competitiveness Ranking (WDCR*) which was created by *IMD World Competitiveness Centre*, the fourth edition of the ranking report of 63 countries was issued in 2020. WDCR measures countries' ability and readiness to adopt digital technologies leading to their economic and social transformation. The ranking of countries depends on three factors: knowledge, technology and future readiness. (IMD World Competitiveness Center, 2020, s. 3). According to the results of IMD World Digital Competitiveness Ranking (WDCR), the Slovak Republic ranked 50th out of 63 countries, down from 47 in 2019. (IMD World Competitiveness Center, 2020) What is the state of digitalization in the Slovak Republic according to the three assessed factors and their subfactors is shown in Figure 1.

In February 2021, the European Parliament and the Council adopted the Regulation (EU) 2021/241 of the European Parliament and of the Council of 12 February 2021 establishing the Recovery and Resilience Facility (RRF) while the scope of application of the mechanism covers six pillars, including digital transformation. On the basis of the RRF European Union Member States have developed recovery and resilience plans. To track digitalization in the European Union, the Digital Economy and Society Index (DESI) is applied. The structure of DESI 2021 is built on four dimensions, while each dimension measures several sub-indeces, they are (sub-indices are in brackets): Human Capital – digital skills (at least basic digital skills, ICT Specialists, Female ICT Specialists), Connectivity (gigabit for everyone i.e. fixed very high capacity network coverage, 5G coverage), Integration of Information Technology (SMEs with a basic level of digital intensity, AI, cloud, big data), and Digital Public Services (digital public services for citizens, digital public services for businesses). (European Commission, 2021, s. 14) Four dimensions of DESI reflect intervention fields set by the RRF. Namely, dimension Human Capital is equivalent to intervention field 3 (Human Capital) of the RRF, dimension Connectivity is the equivalent to intervention field 1 (Connectivity), dimension Integration of Information technology is the equivalent to intervention fields 5 (Digitalisation of businesses) and 6 (Investment in digital capacities and deployment of advanced technologies), and dimension Digital Public Services is the equivalent to intervention field 4 (e-government, digital public services and local digital ecosystems) of the RRF.

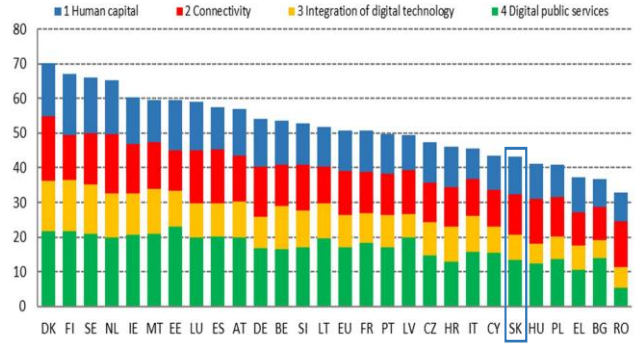


Figure 2 *European Union DESI – overall position of the Slovak Republic*
Source: (European Commission, 2021, p. 3)

The EIB Investment Survey confirmed that most firms surveyed believe that COVID-19 will lead to further acceleration of the use of digital technologies. (Ficarra, Rückert, Virginie, & Weis, 2021), (EIB, 2020a) The current state of digitalization in the Slovak Republic, as assessed by DESI, is shown in Figure Figure **2**. Slovakia has a score of 22 in DESI 2021 among the 27 Member States of the European Union which means that the situation of

digitalization is below the European Union average overall and in four DESI 2021dimensions.

The need for a digital transformation in the European Union is accentuated by the European Investment Bank, which developed a type of composite index - *EIBIS Corporate Digitalisation Index*. The index measures the degree of adoption of digitalization in the EU and the US, which, like previous indices, is composed of several elements, they are digital intensity, digital infrastructure, investment in software and data, investment in organisational and business process improvements, the use of a strategic monitoring system, and the digital outlook, with purpose to summarise indicators on digitalization. (EIB, 2021, s. 6) According to *EIBIS Corporate Digitalisation Index*, the Slovak Republic belongs to the moderate states, as illustrated in the Figure 3.

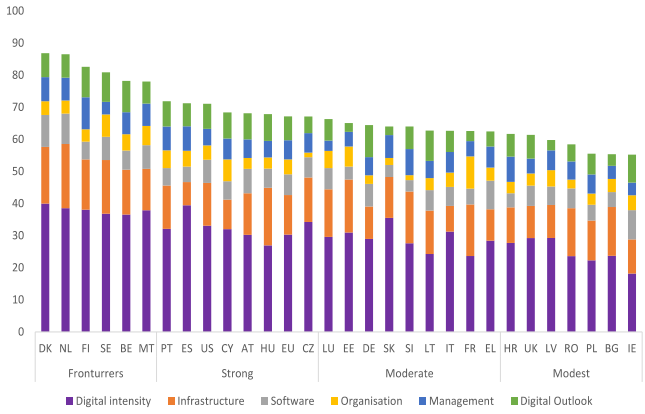


Figure 3 *EIBIS Corporate Digitalization Index, by country*
Source: (EIB, 2021, p. 7)

During the COVID-19 pandemic, it was digitalization that made it possible to continue to work for employees with the reduced mobility necessitated by the pandemic. It has enabled employees to continue working by giving them the opportunity to work remotely - online, thanks to information technology, the internet and digitalization. A questionnaire survey conducted in the Czech Republic found that "home office work use increased significantly compared to the situation before the pandemic. The most significant increase was in the state administration. More than 80% of government executives confirmed the increase, with more than 60% of respondents reporting this in municipalities and nonprofits." (Ministry of Labour and Social Affairs, Czech rep, 2021). In addition, both employers and employees say that they wish to keep their home office work after the COVID-19 pandemic. For example, in an opinion poll commissioned by EON and made by YouGov, "71 percent of respondents who work from home said they would like to continue this way of working in the future. This number is higher compared to the beginning of the pandemic, or a survey last May, when only 58 percent of respondents said so." A similar survey by YouGov made in the UK showed that they "five want to work from home full time after the pandemic." (YouGov, 2021)

This paper aims to examine the regime for remote work, in particular the Home Office regime, its legal definition and impact it has on household or individual expenditures that are required to cover superfluous costs of households or individuals rooted in it. The rest of the paper is structured as follows. Next section provides review of different concepts of remote work and a legal definition of home office work regime in the Slovak republic. Section three is first mapping non-financial effects of remote work, then financial effects of remote work.

2. The different concepts of remote work

In different countries of the world, different labels and definitions are used for remote work, among the most famous there are remote work, telework, work at home, home-based work – see Figure 4 . Sullivan defines out-of-employers' premises work and he set general and project-specific definition of remote work, while in the second case he emphasizes two decisive factors, transportation impact on remote work and one of the most fundamental elements - the use of ICTs. (Sullivan, 2003, p. 3-4) ILO together with Eurofoundation state that there are two key dimensions of telework/ICT-mobile work (T/ICTM) – workplace/mobility and intensity of use of ICT. Based on this, the following categories of out-of-employers' premises work are listed: 1) regular home-based telework, 2) high mobile T/ICTM, 3) occasional T/ICTM, 4) always at employer's premises (ILO; Eurofound, 2017, p. 14)

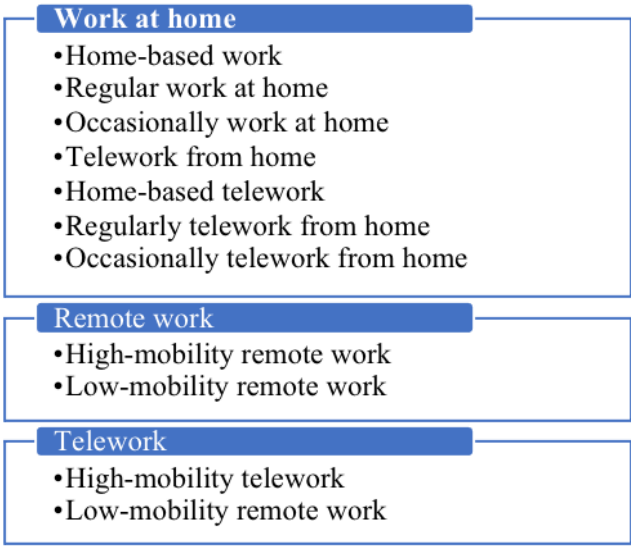


Figure 4 *The different concepts of remote work*
Source: author's own processing based on (ILO, 2020)

In the Slovak Republic, it was in connection with the intensive use of work in the home office mode that the Labour Code No 311/2001 Coll. of Laws was amended on 1 March 2020. In the case of work outside employers'' premises, regular home-based telework, teleworking and, in addition, irregular work from home (home office) are distinguished.

- ***Regular home-based telework*** is regulated in §52(1) to (4) of the Labour Code and its essential feature is that it is carried out from outside the workplace regularly, not just occasionally.
- ***Teleworking*** (high mobile/ICTM) is also set in the Labour Code. In its features it is very similar to homework, especially in that outside the employer's workplace it is carried out regularly, not just occasionally. The difference is that electronic data transmission takes place.
- ***Home office***, (occasional T/ICTM) is regulated in the Section 54(5) of the Labour Code, but its positive legal definition is not provided. On the contrary, it is defined only negatively compared to regular home-based telework and teleworking, namely what is not considered to be regular home-based telework and teleworking even though it is also carried out from an out-of-work premises of employers agreed in the employment contract, usually from home. An essential feature of the Home Office is that outside the employer's workplace it is carried out only occasionally or only in an emergency situation.

3. Effects of remote work

3.1 Non-financial effects

Out-of-employers' premises work convey new effects and challenges of work, not known before. Wheatley, Hardill and Buglass indicate effects and challenges of out-of-employers' premises. Among them there are: career advancements, gender dynamics, mental health, physical remote work environments,

remote team management, remote work, resilient operations, virtual collaboration and teams, work redesign, work, family, and identity, work-life balance, worker well-being (Wheatley , Hardill, & Buglass , 2021). ILO and Eurofound list several groups of effects of T/ICTM work which require both research and the adoption of appropriate regulations: first group, working time: working hours and working time organization (it includes effects of T/ICTM on work duration, effects of T/ICTM on working time organization, effects of T/ICTM on working time autonomy), second group, individual and organizational performance (it includes working time flexibility and work–life balance as a means of improving individual and organizational performance, effects of T/ICTM on work–life balance including its gender dimension), third group, impact of T/ICTM in occupational health and well-being (it includes autonomy and intensity of work, ergonomics, risk isolation, risk of the blurring of the boundary between paid work and personal life – see Figure 5,), and right to be disconnected.

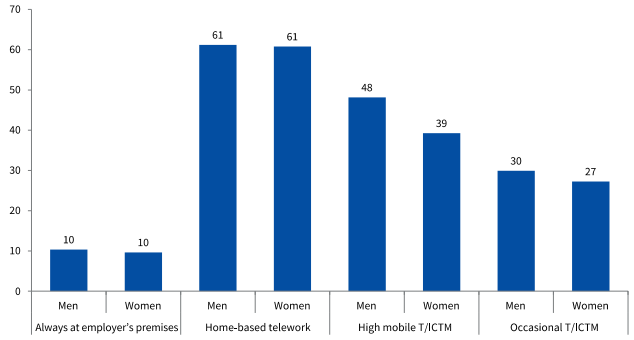


Figure 5 *Employees reporting working in their free time to meet work demands daily and several times a week by type of T/ICTM and gender, EU28 (%)*
Source: (ILO; Eurofound, 2017, p. 30), (Eurofound, 2021)

Empirical literature covers several effects of remote work; however, it does not cover financial consequences of out-of-employers' premises work.

3.2 Financial effects of remote work and Cclassification of employee unpaid costs accompanying home office work mode

The Home Office differs from regular home-based teleworking and teleworking by three characters. Firstly, it is the *occasional* work from home or work from home just and only in an *emergency* situation. Secondly, from a legal point of view, Home Office differs from regular home-based teleworking and teleworking by the agreed place of work, of which it is a compulsory and essential particular of the employment contract, otherwise employment contract would be legally invalid. In the case of occasional work from home (home office) in the employment contract, the main place of work shall indicate the place of employment in employers' premises. Only occasionally, or in emergency situations, and in agreement with the employer, can the employee also carry out work from home, if the nature of the work permits. Nevertheless, the employer must allow employee access to the workplace, employer must provide employee with the technical means necessary for the performance of work, he must protect personal data during electronic data transmission, respect employees' the right to disconnect outside working hours, must prevent the isolation of the employee, enable him/her to educate. Thirdly, unlike regular home-based teleworking or teleworking, where an employee occasionally or in an emergency situation performs work not at the place of work specified in the employment contract, but from home, **the employer is not obliged to reimburse the employee for his home office costs.**

While for the first two categories, i.e., domestic work and teleworking, the employer is obliged to reimburse the employee for the costs associated with the employee working at home, in the case of home office work, which is only occasional work from home in the event of an emergency, the employer is obliged to reimburse the employee for the costs incurred by the performance of work from home.

The third type of remote work, occasional home office work, started to be used at the time of the COVID-19 pandemic. The COVID-19 pandemic has required home office work in many professions where possible.

In this section, we aim to systematically display and summarize the costs of employees who have been working from home for 23 months during the COVID-19 pandemic, i. e. it is no longer about fulfilling the condition of occasional work, on the contrary, employees work long-term and regularly from home.

The costs of staff working in the Home Office during a pandemic can be classified into several groups.

- **Firstly**, the electricity consumption associated with the use of technical security, mainly computers.
- **Secondly**, the cost of connecting a private household to a high-performance Internet, as the performance of work in the Home Office is carried out online in the emergency situation of the COVID-19 pandemic, which requires high data consumption and a sufficiently fast internet, both telecommunications companies charge a higher monthly amount.
- **A third** group of costs of an employee working during the COVID-19 pandemic in home office mode is increased water and sewerage consumption as employee stays at home during the whole day.
- The **fourth** group of home office staff costs are the cost of heat in the apartment and especially the room where the work is carried out during working hours, since, unlike doing work in the workplace, it can no longer regulate daily heat consumption by dampening the heating during its absence.
- The **fifth** group of costs of a home office employee is linked to the need to carry out work from the place where the employee resides, i.e., from an apartment or house which is his own property or he just rents it, and in doing so he can secure an **undisturbed** space reserved for 8.5 hours a day to perform work.
- The **sixth** group of costs is the cost of the equipment with suitable furniture and its wear and tear by frequent use.

Conclusion

As has already been said, work from home which is occasional or during an emergency (Home Office) does not impose an obligation on the employer to reimburse the employee for the costs incurred by the employee in connection with the performance of work from home. **Furthermore, we state and arguments** in favor of specific preferential tax treatment of wages and salaries of employees who have been working long-term from home. Namely, the proposal is to implementation a new tax-deductible item applicable when determining tax base of personal income tax from wages and salaries for employees who have been ordered to work from home due to an emergency situation (COVID-19 pandemic). The following are arguments that justify the proposal:

Firstly, employees of state administrations, ministries and other central government bodies, employees of public administrations and self-governing bodies, as well as university teachers have been performing work home office mode for already 21 months. It is quite clear that the work from home in Home Office mode, has lost one of the essential elements of its legal definition - namely, working from home during a pandemic situation is no longer of an occasional nature, on the contrary, it is regular, and has been changed to a 'new normal'.

Secondly, employers have ordered work from home and do not reimburse the costs of Home Office employees, arguing that in employment contracts with employees signed before the outbreak,

the employer's workplace is listed as the place of work. However, in this case the form over content is preferred.

Thirdly, employers enjoy significant savings during the long term and regularly home office mode – less electricity consumption associated with light and non-connection of computers, printers, less water consumption and sewerage, lower demands on furniture equipment and wear and tear.

References

EIB. (2020a). *EIB Group survey on investment and investment finance 2020. European Union overview*. Online Access: www.eib.org.

EIB. (2020b). *EIB Group survey on investment and investment finance 2020 Country overview . Slovakia*. Online Access: www.eib.org: https://www.eib.org/attachments/efs/eibis_2020_slovakia_en.pdf

EIB. (July 2021). *Digitalisation in Europe 2020-2021: Evidence from the EIB Investment Survey.* Online Access: European Investment Bank: https://www.eib.org/en/about/economic-research/surveys-data/about-eibis.

EIB Group survey on investment and investment finance 2020 Country overview . Slovakia. . (2020). Online Access: www.eib.org.

Eurofoudation. (2017). *Sixth European Working Conditions Survey – Overview report (2017 update)*. Luxembourg: Publications Office of the European Union.

Eurofound. (2021). *European Working Conditions Survey - Data visualisation* . Online Access: Eurofound.europa: https://www.eurofound.europa.eu/data/european-working-conditions-survey?locale=EN&dataSource=EWCS2016&media=png&width=740&question=y15_Q88&plot=euBars&countryGroup=linear&subset=agecat_3&subsetValue=All

European Commission. (2021). *Digital Economy and Society Index (DESI) 2021 Slovakia.* Online Access: Digital Economy and Society: https://digital-strategy.ec.europa.eu/en/policies/desi.

European Commission. (2021). *Digital Economy and Society Index 2021. Thematic chapters* .

European Commission, Eurostat. (2021). *Digital economy and society database (isoc)*. Online Access: Eurostat: https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/database

European Commission. Eurostat. (2021). *European Union survey on the use of ICT in Households and by Individuals.* Online Access: Eurostat: https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/database

European Parliament and Council. (18. February 2021). Regulation (EU) 2021/241 of the European Parliament and of the Council of 12 February 2021 establishing the Recovery and Resilience Facility. *OJ L57*. European Union.

Ficarra, M., Rückert, D., Virginie, A., & Weis, C. (2021). *Digitalisation in Europe 2020-2021: Evidence from the EIB Investment Survey.* Online Access: www.eib.org: https://www.eib.org/attachments/efs/digitalisation_in_europe_2020_2021_en.pdf

Fournier, L. (2013). *Merchant Sharing Theory.* Online Access: https://hal.archives-ouvertes.fr/hal-00908314/document

ILO. (05. June 2020). *Defining and measuring remote work, telework, work at home and home-based work.* Cit. September 2021. Online Access: www.ilo.org: https://www.ilo.org/wcmsp5/groups/public/---dgreports/---stat/documents/publication/wcms_747075.pdf

ILO; Eurofound. (2017). *Working Anytime, Anywhere: The Effects on the World of Work.* Cit. September 2021. Online Access: www.ilo.org: http://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_544138.pdf.

IMD World Competitiveness Center. (2020). *IMD World Digital Competitiveness Ranking (WDCR) for 2020*. Online Access: www.imd.org/wcc.

Mesenbourg, T. L., & Atrostic, B. K. (2001). *Measuring The U.S. Digital Economy: Theory and Practice*. Online Access: https://2001.isiproceedings.org/pdf/1074.pdf.

Ministry of Labour and Social Affairs, Czech rep. (2021). *Home office. Employee and executive experience in the context of the increase in the use of teleworking during the coronavirus pandemic)*. Online Access: Ministry of Labour and Social Affairs: https://www.mpsv.cz/documents/20142/2061970/Vyhodnocen%C3%AD%20dotazn%C3%ADku%20Práce%20z%20domova.pdf/b9e84479-7df2-9f67-3122-7802bb3d9753

Muggah, R. R. (23. Sep 2020). *The dark side of digitalisation*. Online Access: World Economic Forum: https://www.weforum.org/agenda/2020/09/dark-side-digitalization/

Muggah, R., Rohozinski, R., & Goldin, I. (23. Sep 2020). *The dark side of digitalisation*. Online Access: World Economic Forum: https://www.weforum.org/agenda/2020/09/dark-side-digitalization/

Sullivan, C. (2003). What's in a name? Definitions and conceptualisations of teleworking and homeworking. *New Technology, Work and Employment, 18*(3), s. 158–165.

Wheatley , D., Hardill, I., & Buglass , S. (2021). *Handbook of Research on Remote Work and Worker Well-Being in the Post-COVID-19 Era*. IGI Global.

YouGov. (2021). *One in five want to work from home full time after the pandemic*. Online Access: YouGov: https://yougov.co.uk/topics/economy/articles-reports/2021/04/13/one-five-want-work-home-full-time-after-pandemic